THE SUBSURFACE ALTERATION AND MINERALIZATION OF PERMIAN RED BEDS OVERLYING SEVERAL OIL FIELDS IN SOUTHERN OKLAHOMA

By

JERRY DUANE FERGUSON

Bachelor of Science

Oklahoma State University

Stillwater, Oklahoma

1975

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
December, 1977

THE SUBSURFACE ALTERATION AND MINERALIZATION
OF PERMIAN RED BEDS OVERLYING SEVERAL OIL
FIELDS IN SOUTHERN OKLAHOMA

Thesis Approved:

Zuhair Al-Shaieb
Thesis Adviser

John E. Stone

Gary F. Stewart

Norman N. Durham
Dean of the Graduate College

PREFACE

The geochemical manifestations of migrating hydrocarbons and the use of these manifestations in the search for petroleum are topics that have been overlooked in the past and have only recently been recognized and researched. Southern Oklahoma is an excellent area for this type of study. The area contains an abundance of large, shallow petroleum accumulations in anticlinal structures that are exposed at the surface, and much well data are available for each oil field. The detailed examination of rotary drill well cuttings allowed for the mapping of mineral occurrences and alteration zones around several oil fields in the area. Conclusions about the migratory history and the mechanism of accumulation of petroleum have been drawn from these data.

The writer wishes to thank his thesis advisor, Doctor Zuhair Al-Shaieb, for his insight and guidance during this study. Special thanks also are expressed to Doctor Gary F. Stewart and Doctor John Stone for serving as advisory committee members. The help of Eldon Cox of the University of Oklahoma Core and Sample Library also was greatly appreciated.

TABLE OF CONTENTS

Chapter Page

I. INTRODUCTION. 1

II. GEOLOGIC SETTING. 5

1. Structural Setting 5
A. Salient Features. 5
B. Tectonic Evolution. 8
2. Stratigraphic Setting. 10
A. Wolfcampian Units. 12
B. Leonardian Units. 13
Sumner Group 13
(a) Wellington Formation. . . 14
(b) Garber Sandstone. 14
Hennessey Group. 15
(a) Hennessey Shale 16
(b) Post Oak Conglomerate. 16
El Reno Group. 17
(a) Duncan Sandstone. 17
(b) Chickasha Formation . . . 17
Whitehorse Group. 18
(a) Marlow Formation. 18
(b) Rush Springs Sandstone 19
C. Guadalupian Units 20
(a) Cloud Chief Formation. 20
D. Depositional Environments 20

III. SUBSURFACE CHARACTERISTICS OF THE VELMA, EOLA, CHICKASHA, AND ALTUS OIL FIELDS 24

A. The Velma Field. 24
(a) Structure and Stratigraphy. 24
(b) Lithology and Diagenetic Features 28

Chapter | Page

B. The Eola Field. 34
(a) Structure and Stratigraphy 34
(b) Lithology and Diagenetic Features. 39
C. The Chickasha Field 43
(a) Structure and Stratigraphy 43
(b) Lithology and Diagenetic Features. 49
D. The Altus Field 51
(a) Structure and Stratigraphy 51
(b) Lithology and Diagenetic Features. 55

IV. GEOCHEMISTRY AND DIAGENESIS. 60

V. THE MIGRATION AND ALTERATION OF PETROLEUM IN THE VELMA, EOLA, CHICKASHA, AND ALTUS OIL FIELDS. 72

VI. PRINCIPAL OBSERVATIONS AND CONCLUSIONS. 80

REFERENCES CITED. 83

APPENDIX - WELL LOCATIONS AND SAMPLE INTERVALS. 89

LIST OF FIGURES

Figure		Page
1.	Index Map of the Study Area	3
2.	Major Geologic Provinces of Southern Oklahoma. After Pruatt (1975)	6
3.	Stratigraphic Section of the Study Area	11
4.	Cross Section of the Velma Field. After Rutledge (1955)	25
5.	Cross Section of the Velma Field, Showing Permain Units and Boundary of the Pyrite Cement Zone	27
6.	Photomicrograph of a Fine-Grained Sandstone Showing the Replacement of Quartz Grains by Pyrite and the Replacement of Pyrite by Calcite.	30
7.	Photomicrograph of a Fine-Grained Sandstone Showing Euhedral Pyrite in a Calcite Matrix . . .	30
8.	Well Location Map of the Velma Field, Showing Subsurface Pyrite Occurrences Defining the Pyrite Cement Zone.	32
9.	Map of Velma Field, Comparing the Pyrite Cement Zone, Lateral Limits of Productive Areas, and the Permian Anticlinal Axis. Adapted from Rutledge (1955)	33
10.	Map of Velma Field, Comparing the Pyrite Cement Zone and Pre-Permian Faults. Adapted from Rutledge (1955)	35
11.	Map of the Velma Field, Showing Subsurface Native Sulfur Occurrences	36
12.	Cross Section of the Eola Field. From Harlton (1964).	37

Figure | Page

13. Photomicrograph of a Fine-Grained Sandstone Showing the Replacement of Quartz Grains and Calcite Cement by Pyrite. 41

14. Photomicrograph of a Fine-Grained Sandstone Showing the Replacement of Quartz Grains by Calcite Cement 41

15. Well Location Map of the Eola Field, Showing Subsurface Pyrite Occurrences Defining the Pyrite Cement Zone. 42

16. Map of the Eola Field, Comparing the Pyrite Cement Zone and the Lateral Limits of Production. 44

17. Map of the Eola Field, Comparing the Pyrite Cement Zone and Pre-Permian Faults 45

18. Cross Section of the Chickasha Field. After Herrmann (1961) 47

19. Cross Section of the Chickasha Field, Showing Permian Units and the Boundary of the Pyrite Cement Zone 48

20. Photomicrograph of a Fine-Grained Sandstone Showing the Replacement of Quartz Grains by Pyrite and Calcite and the Replacement of Calcite by Pyrite 50

21. Photomicrograph of a Fine-Grained Sandstone Showing the Replacement of Quartz Grains by Pyrite. 50

22. Well Location Map of the Chickasha Field, Showing Subsurface Pyrite Occurrences Defining the Pyrite Cement Zone. 52

23. Map of the Chickasha Field, Comparing the Pyrite Cement Zone and the Lateral Limits of Production. 53

24. Map of the Chickasha Field, Comparing the Pyrite Cement Zone and the Pre-Permian Structures. After Ryniker and others (1959) 54

Figure Page

25. Cross Section of the Altus Field. From Ryniker and others (1959). 56

26. Stability Field Diagram for the Ferric-Ferrous System. From Hem and Cropper (1959). Ground Water Field from Baas Becking and others (1960). Connate Water Field from Collins (1969) 61

27. Stability Field Diagram for Iron Minerals. From Garrels and Christ (1965). 63

CHAPTER I

INTRODUCTION

Southern Oklahoma is an area of vast hydrocarbon accumulations, and the search early in this century for these hydrocarbons resulted in detailed mapping of the surficial geology of the area. Many anticlines have been mapped on the surface, and most of these structures have been found to contain petroleum accumulations. A common characteristic observed on the surface of many of these structures is a change in color of Permian red beds. Reeves (1922) was the first to report this phenomenon in his investigation of the Cement oil field in Caddo County. He observed the normally brownish-red Permian Whitehorse Sandstone to change color to pink, white, and yellow two-thirds of the way up the flanks of the anticline. Harlton (1960) described similar alterations along the axes of the Carter-Knox, Velma, and Eola anticlines.

The first comprehensive investigation of the rock alteration was by Donovan (1974) in the Cement oil field. An extensive geochemical analysis was conducted, and the author found that the altered red beds were underlain by oil productive zones. The color changes were brought about by the reduction of iron by migrating hydrocarbons. Thus, the bleached zone on the crest of the Cement anticline was found to be indicative of the presence of hydrocarbons at depth.

In an evaluation of the uranium potential of south-central Oklahoma, Olmsted (1975) found anomalous groundwater uranium concentrations associated with oil producing anticlines having altered or bleached Permian red beds at their crests. He indicated that the geochemical mechanism responsible for the alteration of the red beds at Cement also was responsible for the emplacement of uranium mineralization along the crest of the structure. Similar alteration zones were recommended as possible sites of uranium deposits.

Although Donovan (1972) reported that the alteration of red sandstone units extended into the subsurface, no investigation has been undertaken to study the subsurface manifestations of the rock bleaching observed on the surface. Therefore, the purpose of this investigation is to describe the subsurface alteration of Permian strata overlying the crests of several oil-producing structures in southern Oklahoma and to determine if the geochemical process outlined by Donovan for the Cement area can be applied to areas having similar structural and stratigraphic features.

Four oil fields in southcentral and southwestern Oklahoma were chosen for investigation. These fields are the Chickasha field in Grady County, the Velma field in Stephens County, the Eola field in Garvin County, and the Altus field in Jackson County (Figure 1). All of the fields are overlain by Permian red beds.

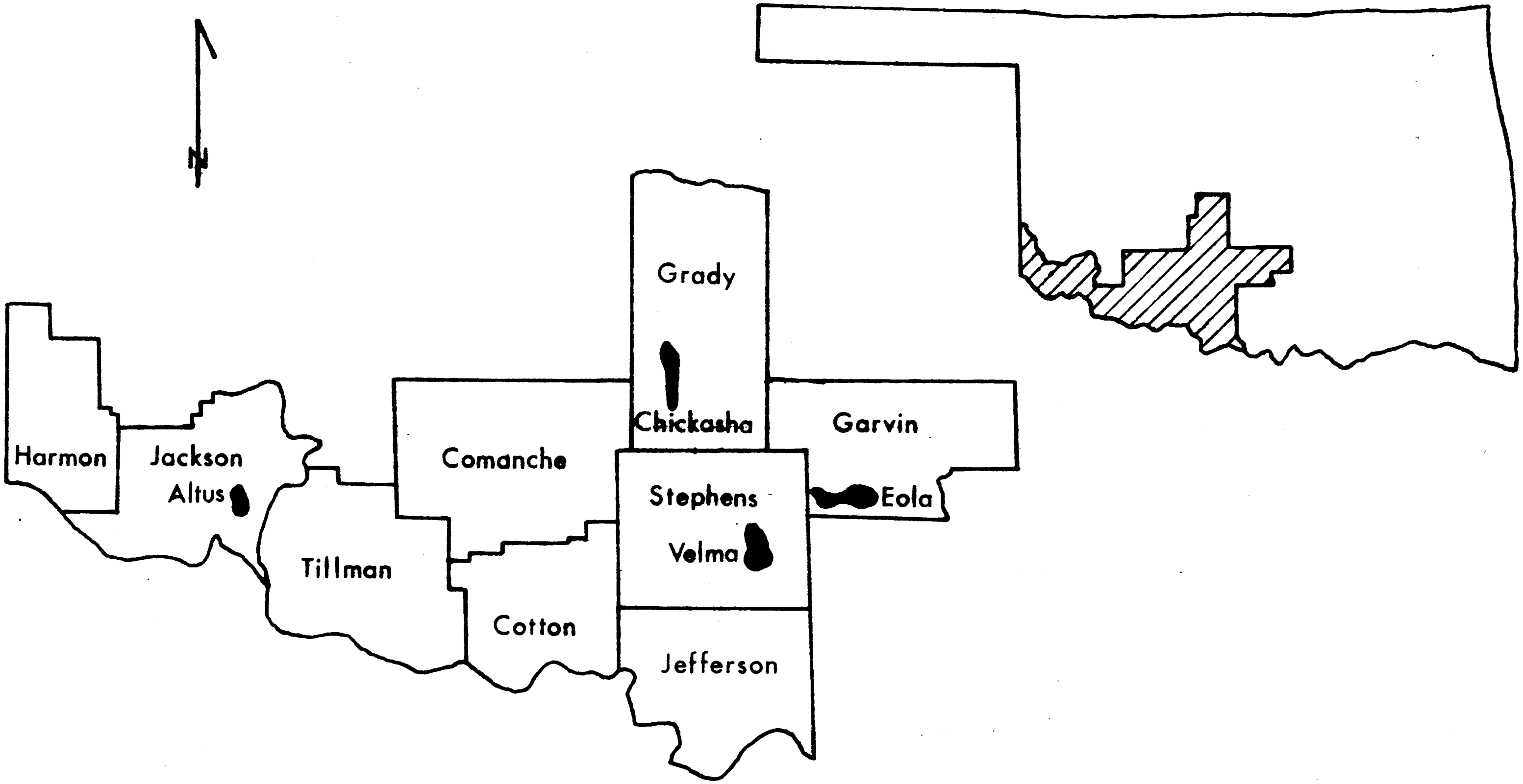

Figure 1. Index Map of the Study Area

Well cuttings throughout all of the designated oil fields were examined to study subsurface alteration. The cuttings were examined using a 40 power binocular microscope, and a sample log was made of each well. The following characteristics were recorded for each sample interval: depth, lithology, grain size, color, cements, and minor constituents. Sample intervals were usually at ten foot spacings. Grain size was determined using the Wentworth scale and color was defined by the Rock Color Chart (Goddard and others, 1963).

Thin sections of sandstones were made to determine cement types and paragenesis. The sections were stained with alizarin red S and potassium ferricyanide solutions to determine the ratio of calcite to dolomite and the amount of iron in the carbonate cements (Evamy, 1963).

Maps were made of the occurrences of different cements and minor constituents to determine if any mineral zonations existed. Cross sections were prepared from electric log data, and mineral occurrences were plotted on the vertical sections to determine the shape and position of the zone boundaries.

CHAPTER II

GEOLOGIC SETTING

1. Structural Setting

A. Salient Features

Southern Oklahoma is a part of the southern boundary of the North American craton (Ham and Wilson, 1967). However, in its relation to the geology of the rest of the craton, the area is unique. This region is the site of the thickest accumulation of Paleozoic sediments in the central United States. It also is the center of large petroleum accumulations.

Southern Oklahoma can be divided into three major structural provinces, each of which is named from its associated uplift. These are the Wichita province, the Arbuckle province, and the Ouachita province. The structural elements of all the provinces are shown in Figure 2.

The Wichita province includes the Wichita Mountains in southwestern Oklahoma and continues in the subsurface into Texas, where it is called the Amarillo uplift (Figure 2). Exposed in this uplift is an igneous complex of mafic and felsic rocks radiometrically dated as Cambrian. South of the uplift is the shallow Hollis or Hardeman basin. This basin

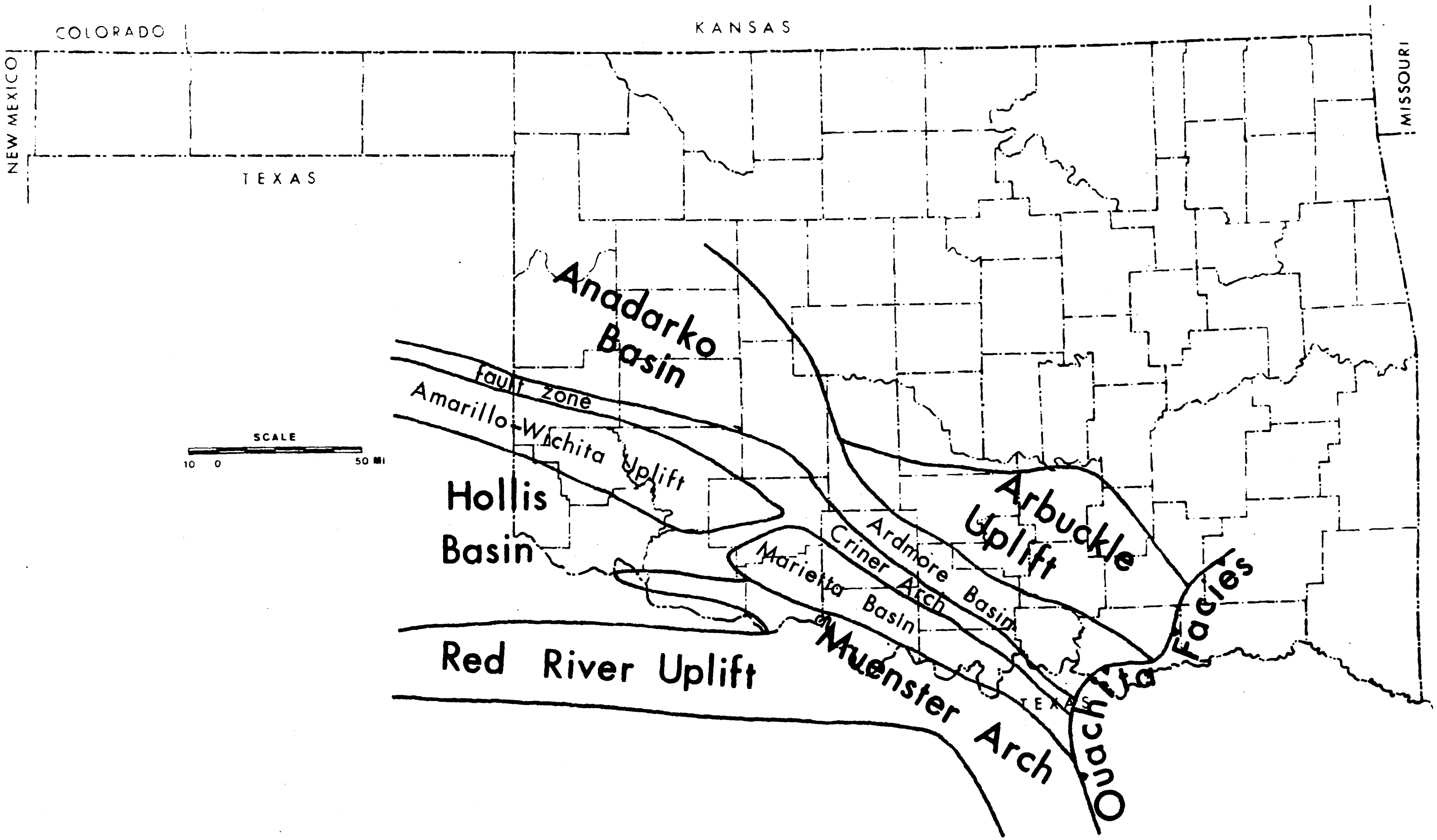

Figure 2. Major Geologic Provinces of Southern Oklahoma. After Pruatt (1975).

is approximately 3 km deep and lies north of the Red River uplift, an east-west trending structural high consisting of metamorphic and metasedimentary rocks. North of the Wichita uplift lies the Anadarko basin, the deepest midcontinent basin. The basin is separated from the Wichita Mountains by a zone of high angle reverse faults 10 to 20 km wide. The deepest part of the basin abuts this zone, forming an asymmetric elongate trough running parallel to the uplift. The Anadarko basin is approximately 18 km deep.

Southeast of the Wichita province lies the Arbuckle province including, from north to south, the Arbuckle uplift, a roughly triangular feature covering 1800 km^2, the Ardmore basin, the Criner arch, the Marietta basin, and the Muenster arch (Figure 2). The features extend southeastward and are concealed by overthrusts of the Ouachita province.

The Arbuckle uplift can be divided into two zones, an uplifted basement block to the northeast known as the Tishomingo uplift and a broad anticlinal feature to the southwest known as the Arbuckle anticline. The dividing line between two areas is the Reagan fault, a northwest trending fault with approximately 11 km of displacement, downthrown to the south.

The Arbuckle anticline is a surface expression of similar structures found in the subsurface southward in the Ardmore basin. Strata in the basin are tightly folded, the basin now occupying two-thirds of its original width. The southern boundary of the Ardmore basin is the Criner arch. This structural high is an eastward extension of the Wichita uplift. The Marietta basin is situated south of the Criner arch and is approximately 6 km deep. The basin contains minor internal folding.

The Ouachita province is the easternmost structural province in southern Oklahoma and comprises the Arkoma basin to the north and the Ouachita Mountains to the south. The Ouachita Mountains are an elongate belt of folded and thrust-faulted Palezoic rocks.

B. Tectonic Evolution

A major structural trough was developed on the basement complex in southern Oklahoma during Late Precambrian or Early Cambrian time and was a persistent negative feature throughout the Palezoic Era. This trough has been named the Southern Oklahoma aulacogen by Pruatt (1975). An aulacogen is defined as a transverse linear trough that extends far into the interior of a foreland platform and is believed to represent the failed arm of a three-armed radial rift system or triple junction (Hoffman, Dewey and Burke, 1974).

Wickham and others (1975) recognize three stages of structural activity within the Southern Oklahoma aulacogen: A rifting stage from latest Precambrian through Middle Cambrian time, a subsiding stage from Late Cambrian through Early Devonian time, and a deforming stage from Late Devonian through Early Permian time. Powell and Phelps (1977) present evidence that the aulacogen developed within an earlier

Precambrian zone of crustal weakness, a rejuvenation of which evolved as the aulacogen.

The rifting stage was characterized by extentional normal faulting, the extrusion of basalts and rhyolites, and the emplacement of gabbros and granites. At the end of this stage the early aulacogen was a graben floored by igneous and metasedimentary rocks.

The subsidence stage is marked by a marine transgression in Late Cambrian time followed by the deposition of 3100 m of carbonate rocks through Early Devonian time. Subsidence was accomplished by vertical displacements of several kilometers along the bounding faults of the graben.

The deformational stage was characterized by a compressional phase during which marked subsidence of the Anadarko-Ardmore basins occurred simultaneously with significant episodic uplift of the Wichita-Criner and Arbuckle uplifts. The compressive phase is interpreted by Hoffman and others (1974) to be related to subduction resulting in formation of the Ouachita system. Deformation was accompanied by rapid sedimentation in basins contiguous to positive areas.

Uplift of the Wichita Mountains and the Criner arch took place in early Morrowan, early Atokan, and middle Desmoinesian time (Tomlinson, and McBee, 1959) and resulted in the dividing of the uniform aulacogen trough into the Anadarko and Ardmore basins on the northern edge of the uplift and the Hollis and Marietta basins on the south side of the uplift. The Red River and Muenster arches also were uplifted at these times (Van der Gracht, 1931).

In middle Virgilian time the Arbuckle Mountains were uplifted and rocks within the Ardmore basin were folded. Subsidence of the Anadarko basin did not cease, however, and sedimentation went on through Guadalupian or Ochoan time (Ham and Wilson, 1967).

Although tectonic activity had essentially ceased by the end of Pennsylvanian time, minor folding of Permian strata over older Pennsylvanian structures did take place. Areas in which Permian rocks are observed to be slightly folded at the surface included Velma, Carter-Knox, Healdton, and Cement.

Faulting, folding, and refolding of Paleozoic rocks northwest of the Arbuckle Mountains during the Wichita and Arbuckle orogenies provided many anticlinal traps for the accumulation of hydrocarbons. These structures are all aligned along the general northwest-southeast structural trend and have many characteristics in common. The folds are generally asymmetric and are overturned to the north. They are disharmonic folds, showing a decrease in structural complexity at depth. Thrust faults parallel to the anticlinal axes are common and are associated with normal faults at an oblique angle to the structural trend.

2. Stratigraphic Setting

The Late Paleozoic stratigraphic column utilized in this investigation is after Miser (1954; Figure 3). The

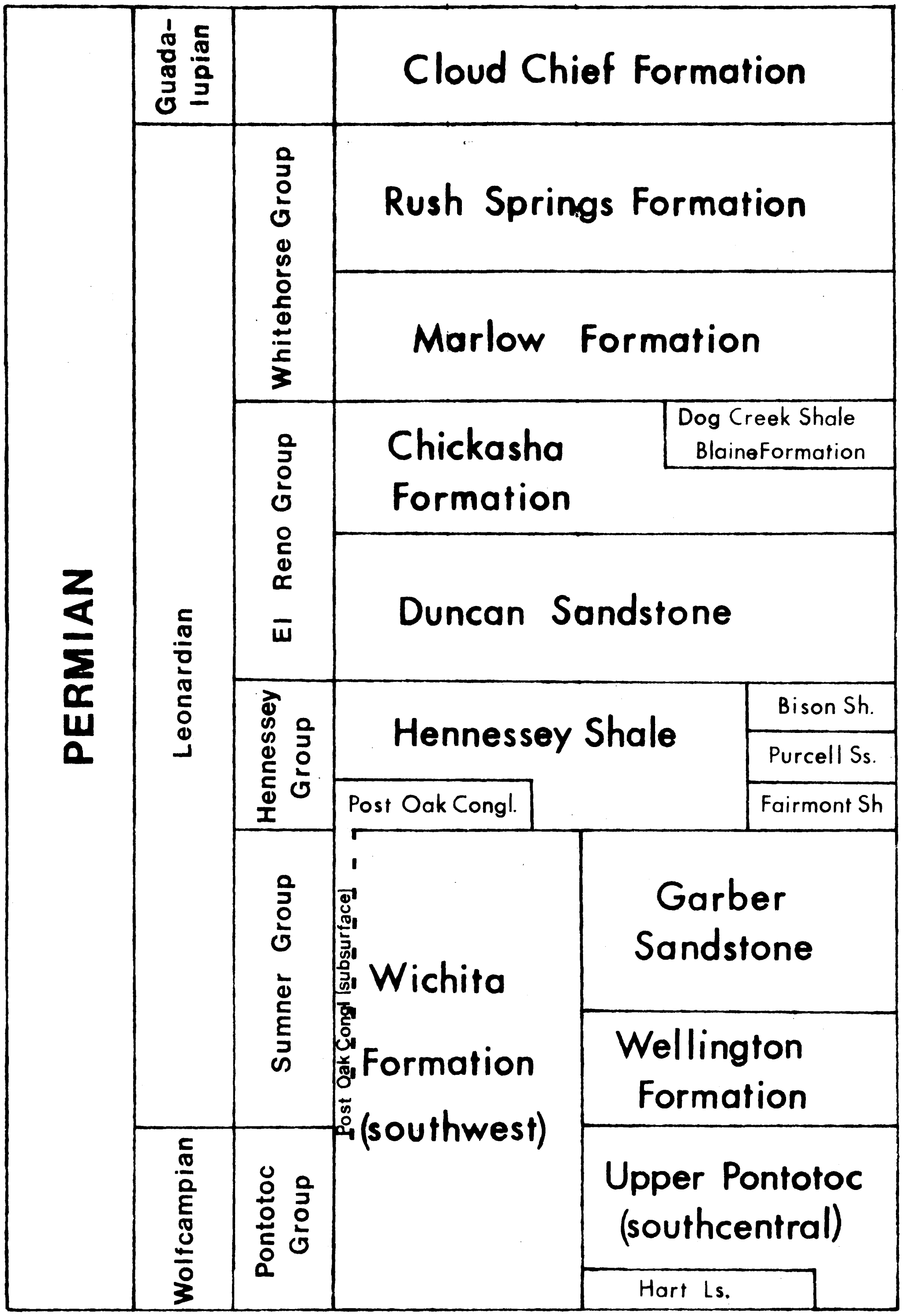

Figure 3. Stratigraphic Section of the Study Area

Oklahoma Geological Survey recently has proposed a new classification for the Late Paleozoic (Fay, 1968). Apparently this new classification has not been applied in the subsurface, and this discrepancy has necessitated the use of the older classification.

In the southern part of Oklahoma the boundary between the Pennsylvanian and Permian systems is not clearly defined due to continuous deposition of clastic sediments of similar lithology (MacLachlan, 1967). The following description attempts to adhere to the predominate opinion.

Rocks encountered in the subsurface in the areas studied range in age from Cambrian through Upper Permian. However, the sequence of altered strata is confined to rocks of Permian age. These rocks range in age from the Wolfcampian Pontotoc Group through the Leonardian Rush Springs Sandstone. Therefore, emphasis is placed on Permian stratigraphy.

A. Wolfcampian Units

In Garvin, Stephens, and Carter counties the Wolfcampian Series is represented by the upper part of the Pontotoc Group. The Pontotoc Group consists of a series of red beds, arkosic sandstones, limestone conglomerates, and limestones of which the Hart Limestone is the lowest formation that extends continuously around the west end of the Arbuckle Mountains. The Hart Limestone is commonly considered the base of the Woldcampian Series. Tomlinson (1930) described the Hart Limestone as an unfossiliferous, gray limestone which is as thick as 61 m. This limestone pinches out in southern Carter County and is represented by associated red shales containing small, roughly spherical limestone concretions.

The maximum thickness of the Pontotoc Group in Carter County is estimated by Tomlinson (1930) to be 122 m, whereas a thickness of 137 m is reported by Dott (1930) in Garvin County. The Hart Limestone is present in only the eastern one-third of Garvin County and grades westward into red shales and gray arkosic sandstones. This westward facies change is reflected in Gouin's (1930) description of the Wolfcampian rocks in Stephens County in which he was unable to distinguish any limestones in the Pontotoc Group.

In southern Oklahoma from Stephens County westward, the Wolfcampian Series is represented by the Wichita Formation which consists of a variable thickness of massive brown sandstones containing chert and quartz pebble lenses, interbedded purplish-maroon shales, and some baritic concretions (Gouin, 1956).

B. Leonardian Units

In southcentral Oklahoma the Leonardian Series is represented by the Sumner Group, the Hennessey Group, and the El Reno Group.

Sumner Group

The Sumner Group has been subdivided into the Wellington Formation and the overlying Garber Sandstone in southcentral

Oklahoma, while the upper part of the Wichita Formation is considered to be the equivalent of the Sumner Group in the southwestern part of the state.

(a) Wellington Formation. The Ryan Sandstone Member is found at the base of the Wellington Formation. Bunn (1930) described the sandstone as being massively to thinly-bedded and 5.2 to 18.5 m thick in Jefferson County. At the northwest end of the Arbuckle Mountains in Garvin County, the Ryan Sandstone Member consists of two massive sandstones seperated by a shale interval. Dott (1930) described the lower sandstone as massively bedded, of medium hardness, and brown to black in color. This lower unit is approximately 11 m thick. The overlying shale is composed of 19 m of red shale containing several thin sandstone lenses. The upper unit is a sandstone which is thinner bedded and better cemented than the lower sandstone.

The remainder of the Wellington Formation consists of more than 30 m of reddish-brown to gray, blocky shales and siltstones. Sandstone lenses of buff to gray friable sandstone are common in this upper sequence. The total thickness of the Wellington Formation in Garvin county is 88 m.

(b) Garber Sandstone. The rocks of the Garber Sandstone in southcentral and southwestern Oklahoma are distinguished from those of the Wellington Fromation and older Permian rocks by their reddish-brown color. The base of the formation is marked by the Asphaltum Sandstone Member. Bunn (1930) described this unit as a series of gray to buff, calcareous sandstones, generally massive, friable, and medium-grained, but locally laminated and thinly bedded. The thickness varies from 6.1 to 15.2 m and consists of one or more members separated by intervening shale beds. Bunn also noted the occurrence of a nodular limestone conglomerate in some areas. Munn (1914) mapped this conglomerate as the Auger Lentil.

Above the Asphaltum Sandstone Bunn (1930) divided the Garber into two units. The lower unit is a 37 m sequence of sandstone. However, northward from Jefferson County the lower 15 m grades into shale. This sandstone caps many bluffs in the southcentral part of the state.

The lower unit is a sequence of shales and a few sandstones. The entire unit is red and is approximately 36 m thick. Total thickness of the Garber Sandstone in southcentral Oklahoma is about 72 m.

Hennessey Group

In western Oklahoma the Hennessey Group has been divided into the Fairmont Shale, the Purcell Sandstone, and the Bison Shale. In the western portion of the study area the group has not been divided and is known as the Hennessey Shale. On the flanks of the Wichita Mountains, the Post Oak Conglomerate is considered to be the equivalent of the Hennessey Group

(Fay, 1968), while Miser (1954) considers it equivalent to the upper part of the Wichita Formation.

(a) Hennessey Group. The lower part of the Hennessey Group consists of a sequence of reddish-brown blocky shales. This shale unit was named the Fairmont Shale by Aurin, Officer, and Gould (1926), and a 12 to 24 m thickness of this unit was mapped in Garvin County by Hart (1974).

Between the lower Fairmont Shale and the upper Bison Shale lies a succession of highly lenticular cross-bedded sandstones. This sequence was named the Purcell Sandstone by Green (1936). Hart (1974) also mapped this sandstone in Garvin County and describes a 27 to 46 m series of reddish-brown to maroon, fine to coarse-grained sandstone with some intervening shales and mudstone conglomerates.

The Bison Shale makes up the top of the Hennessey Group and consists of 15 to 27 m of gray to reddish-brown, calcareous, blocky shales. West of Duncan, Oklahoma the Bison Shale and Purcell Sandstone are undifferentiated, and the series is mapped as the Hennessey Shale. Thickness of the formation ranges from 46 to 183 m across the southern part of the state.

(b) Post Oak Conglomerate. The Post Oak Conglomerate crops out in an area surrounding and adjacent to the Wichita Mountains. This unit was described by Chase (1954) as a granite boulder conglomerate and arkose. Close to the mountains, the conglomerate is comprised of granite cobbles and boulders interbedded with cross-bedded arkose. Short distances away from the mountains the boulder facies grades into a gravel facies that contains a greater proportion of arkose lenses. Farther from the mountains the conglomerate grades into an arkose and arkosic sandstone interfingering with the Hennessey Shale.

El Reno Group

The rocks of the El Reno Group overlie those of the Hennessey Group. The group is a wedge-shaped unit that has been subdivided by Gould (1924) into the lower Duncan Sandstone and the Chickasha Formation. This group thins northwestward towards the Anadarko basin.

(a) Duncan Sandstone. The Duncan Sandstone is maximally 190 m thick in Stephens and Garvin counties, where it forms a prominent scarp. The formation consists of two or three units of buff to gray-green, fine-grained to very fine-grained sandstone, with some dolomitic lenses (Self, 1966). Brown (1937) described the lower 7.6 m of the formation as being highly cross-bedded and conglomeratic. The top of the formation contains some chert conglomerate and arkosic material, and its buff color distinguishes it from the overlying Chickasha Formation.

(b) Chickasha Formation. The Chickasha Formation varies in thickness from 46 to 76 m. Gouin (1926) measured 61 m in Stephens County. Brown (1937) describes the lower part of the formation as conglomeratic and highly cross-bedded. The upper portion of this formation is separated from a lower sandstone by approximately 15 m of uncemented pink sandstone (Gould, 1924). The upper sequence consists of 49 m of highly cross-bedded sandstones and conglomerates with thin red shale intervals. The top bed of formation is a cross-bedded sandstone at least 7.6 m thick.

The Chickasha Formation grades laterally into and is overlain by the Dog Creek Shale and Blaine Formation in a northwestward direction from Stephens County. The boundary between the Chickasha Formation and the Dog Creek-Blaine formations is marked by a conglomeratic mudstone in northern Grady County and a dolomitic to gypsiferous sandstone in the southern part of the county.

Whitehorse Group

Overlying the El Reno Group is the Whitehorse Group which has been subdivided into the lower Marlow Formation and the overlying Rush Springs Sandstone. The group comprises reddish-brown fine-grained sandstone and siltstone with some thin dolomite and gypsum beds. Thickness of the group was reported as 133 m in Grady County by Fay (1964).

(a) Marlow Formation. The Marlow Formation is about 40 m thick in Grady County (Davis, 1955). The formation consists of moderate reddish-brown, even-bedded, fine-grained, silty sandstones and shales. Several white gypsiferous layers occur but are not traceable for long distances. Satin-spar gypsum is distributed randomly throughout the unit.

The Verden Sandstone Member is near the middle of the formation and crops out in both Grady and Stephens counties. This member is 3 m thick and is characterized by thick beds of medium to coarse-grained sandstone with calcium-carbonate cement. These beds are interbedded with thin layers of fine-grained, horizontally laminated shale. The sandstone beds are highly cross-bedded.

Two dolomite beds occur at the top of the Marlow Formation. These beds were named by Evans (1931) as the Upper Relay Creek and Lower Relay Creek Members. In Grady County these two beds are separated by 4.6 to 6 m of red sandstone and shale and are paper thin to .1 m thick.

(b) Rush Springs Sandstone. The Rush Springs Sandstone overlies the Marlow Formation and is from 46 to 101 m thick. Davis (1955) reports a thickness of 51 m in northern Stephens county. The formation thins in a northwestward direction towards the Anadarko basin.

In Grady and northern Stephens counties the Rush Springs Sandstone is an even to highly cross-bedded, light-brown, soft, silty sandstone. Tanaka and Davis (1963) describe a few calcareous sandstones in the lower part of the formation.

These calcereous beds range from .15 to 1.8 m in thickness. Very coarse, frosted, spherical grains are also common in the lower part of the formation. All grains are covered with an iron oxide stain.

A silty shale phase is present within the formation in Grady County. This phase forms a wedge that becomes sandier westward and is moderate reddish-brown, while the adjacent sandstone is light brown. West of Grady County sandstone beds within the formation grade into gypsum beds.

C. Guadalupin Units

(a) Cloud Chief Formation

Overlying the Rush Springs Sandstone is the Cloud Chief Formation. This formation caps topographic highs in the Chickasha area. Locally a thickness of 4.5 m is obtained, but generally only a fraction of a meter is present. The formation consists of irregular, impure gypsum beds interbedded with shales (Fay, 1969).

D. Depositional Environments

Permian rocks throughout southern Oklahoma record the filling of basins which had been existent since Cambrian time and the final dessication of the shallow seas present in these basins. In general, upward through the section, environments of deposition progress from normal marine, to restricted marine, to marine mudflat - evaporite conditions (MacLachlan, 1967). Evaporites were first deposited in Leonardian time. In the eastern part of the Anadarko basin shelf conditions existed, and an influx of terriginous sediments primarily from the Ouachita uplift allowed the formation of a thick clastic sequence of shales and sandstones (Ham and Wilson, 1967). Adjacent to the Wichita and Arbuckle mountains, thick wedges of arkose and conglomerate were deposited as alluvial fans that extend for short distances into the continguous basins. These alluvial fan deposits are represented by limestone conglomerates of the Pototoc Group adjacent to the Arbuckle Mountains and the Post Oak Conglomerate adjacent to the Wichita Mountains.

Flood (1969) concluded that Lower Permian sandstone lenses in western Jefferson County were of fluvial origin, and that the surrounding siltstones and shales represent flood-plain and delta-flat deposits. The lithology and geometry of the Lower Permian sandstones in southcentral Oklahoma are similar to those described by Flood and are believed to have been deposited under the same conditions. Calcareous sandstones and clay-pebble conglomerates in Lower Permian rocks are evidence of brief marine incursions. Paleocurrent indicators define a northwesterly flow of the streams, and the trend of channel sandstones is in the same direction. This current direction implies a source area to the southeast. Two positive areas, the Ouachita and Arbuckle uplifts, were present in southeastern Oklahoma at the time of deposition. Rhyolite and granite fragments from the Arbuckle Mountains are present in rocks of Wolfcampian age only, and Flood (1969) concluded that by the end of this epoch the contribution of sediments from the Arbuckle Mountains was minimal. The Ouachita uplift was the major sediment source throughout the rest of Permian time in southern Oklahoma.

In southwestern Oklahoma the Wichita Mountains were part of an archipeligo that acted as a barrier between the Anadarko and Hollis basins (MacLachlan, 1967). The mountains did supply detritus to the basins, as a series of coalescent alluvial fans composed of granite and rhyolite boulders. These boulder conglomerates make up the Post Oak Conglomerate, which interfingers with finer-grained sediments in both basins. The Wichita Mountains apparently were only a localized sediment source after Wolfcampian time.

Fay (1964) considers the Chickasha and Duncan formations to have been deposited as a delta of a large river that flowed northwestward from the Ouachita Mountains. This delta was named the Tussey delta by Green (1937).

The Marlow Formation apparently was deposited in a shallow sea that transgressed over the subsiding Tussey delta. Fay (1964) interpreted the depositional environment as being gradational between deltaic and shallow-brackish marine, while MacLachlan (1967) postulated a marine-mudflat environment.

A large influx of sand-sized material, possibly from uplift of the Ouachita Mountains, led to deposition of the Rush Springs Sandstone in the shallow Permian sea (Davis, 1955). Sea level fluctuations exposed the sands periodically, and eolian conditions piled the sand into dunes (O'Brien, 1963).

The onset of evaporative conditions produced gypsum of the Cloud Chief Formation (Ham, 1960).

CHAPTER III

SUBSURFACE CHARACTERISTICS OF THE VELMA, EOLA, CHICKASHA, AND ALTUS OIL FIELDS

A. The Velma Field

(a) Structure and Stratigraphy

The Velma oil field is located in the eastern one-half of T.1S., R.5W., Stephens County, Oklahoma, and in adjacent parts of townships to the south and east (Figure 1). The field is situated on the eastern margin of the Anadarko basin.

The structure is essentially a northwesterly-trending asymmetrical anticline with a horst block along its axis (Figure 4). Structural deformation began during Morrowan time, near the end of the Wichita orogeny, and continued through the Arbuckle orogeny (Rutledge, 1954). The Velma structure was uplifted, folded, and faulted during this interval. Marine beds were deposited over the structure during post-Morrowan time until the onset of the Arbuckle orogeny in Missourian and Virgilian time. Flanks of the anticline were steepened, the central horst emerged from the compressed fold, and movement along high-angle reverse faults parallel to

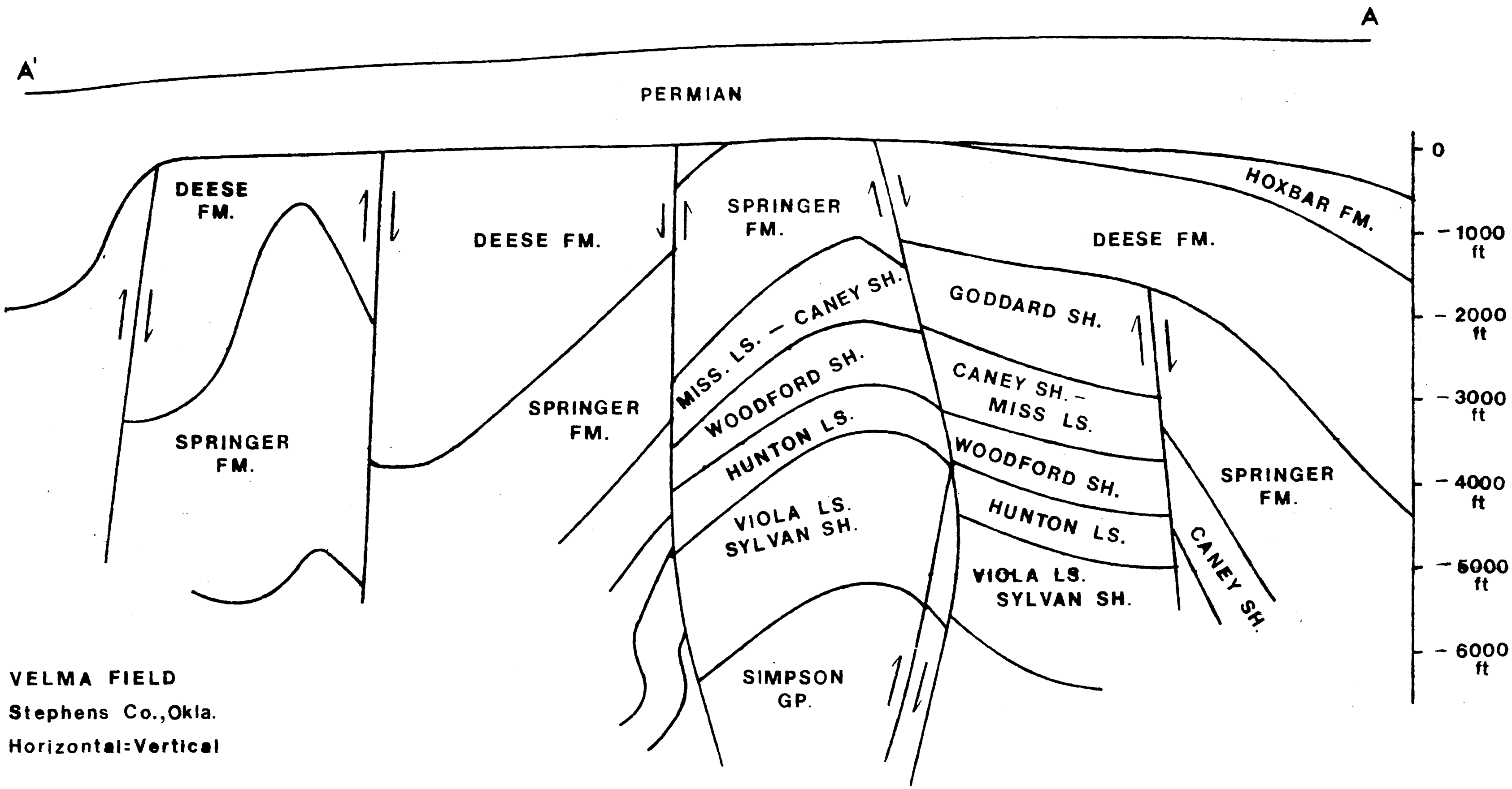

Figure 4. Cross Section of the Velma Field. After Rutledge (1955).

the anticlinal axis divided the anticline into a series of tilted fault blocks. Following the end of the major orogenic activity, approximately 300 m of Permian shales and sandstones were deposited over the structure. Minor structural deformation continued during Early Permian time, however. Permian strata are observed to form a prominent north-northwest-tending anticlinal ridge at the surface. The axis of this surficial anticline is located directly above the central horst of the underlying structure.

Oil productive zones within the Velma field range in age from Ordovician to Permian. Important producing horizons include the Simpson Group of Ordovician age, the Hunton Group of Devonian age, the Sycamore Limestone of Mississippian age, and several Pennsylvanian units including the Springer, Deese, and Hoxbar formations. The Springer Formation generally is considered the most important producing horizon in the field. This formation is truncated at the crest of the anticline and is overlain by Permian and younger Pennsylvanian strata. Permian sandstones have produced oil and some gas from depths of 100 to 300 m (Rutlege, 1954).

Permian units within the area include the Wichita Formation, Wellington Formation, and Garber Sandstone. A cross section of these formations is shown in Figure 5. Thickness of the section ranges from 360 m over the structural crest to 800 m down the flanks of the anticline. The section is not faulted, and an unconformity is present at its base.

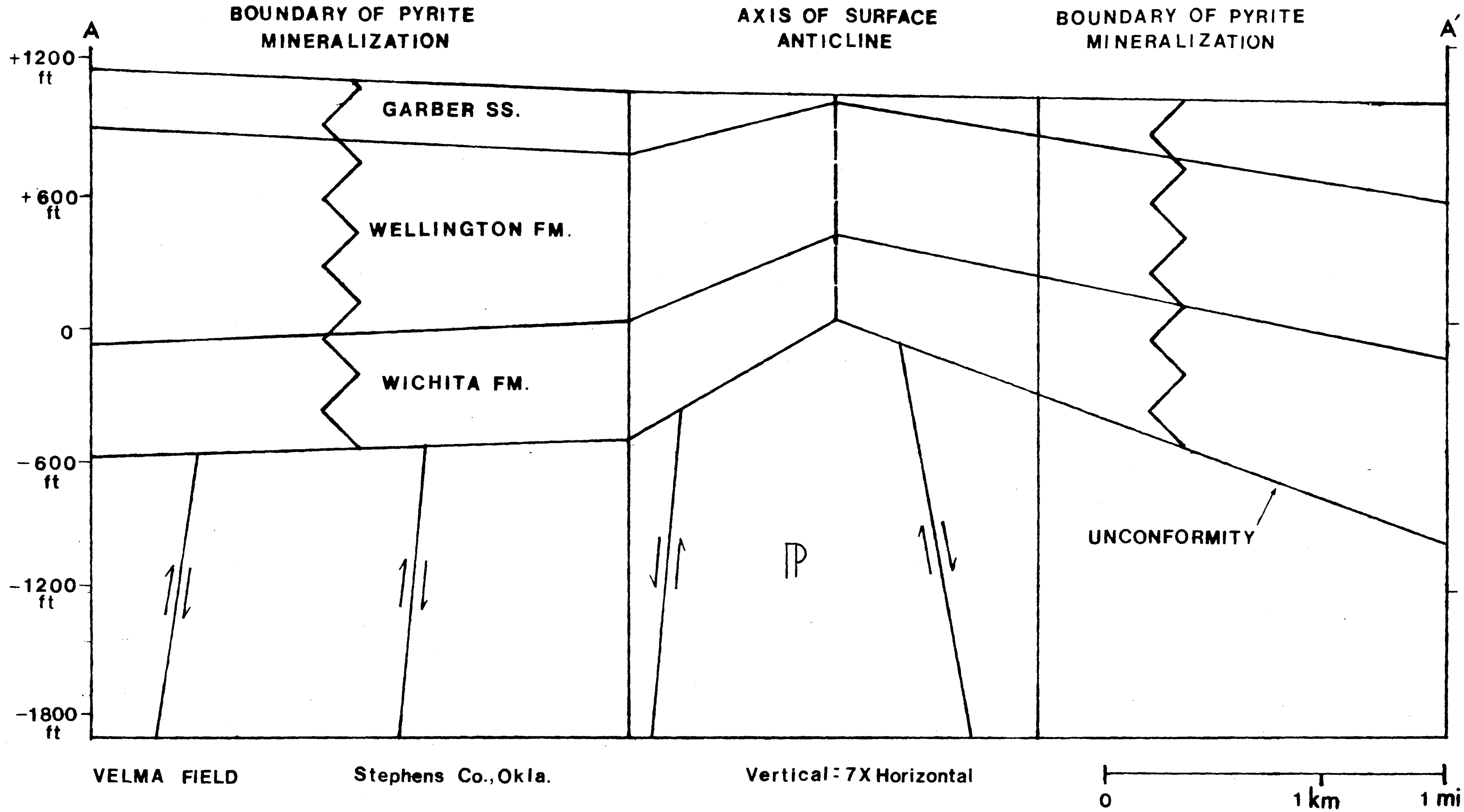

Figure 5. Cross Section of the Velma Field, Showing Permian Units and Boundary of the Pyrite Cement Zone

(b) Lithology and Diagenetic Features

Bit cuttings from 40 wells were examined to study the characteristics outlined in the introductory chapter. Only Permian rocks were inspected. The boundary between Permian and Pennsylvanian rocks was generally marked by black marine shales and limestones which are known not to occur in the Permian section. In all of the wells the sample interval began within at least 180 m of the surface, and cuttings were available from the surface downward in 14 wells. The Permian-Pennsylvanian boundary was encountered in 31 wells. In areas where a completely sampled section was not available, an attempt was made to find adjacent wells in which the missing section was represented.

The rocks observed in the field were claystone, shale, siltstone, and sandstone. Claystone and shale were the most abundant rock types, making up approximately 60% of the total rocks examined. Siltstones were the least common, composing about 10% of the total. Sandstones made up the remainder, and grain size ranged from very fine to medium (.0625 - .50 mm). Fine-grained sandstones were the most abundant by far, and very-fine grained and medium-grained sandstones were sparse. The sandstones were all quartz arenites (Folk, 1974).

All of the claystones, shales, and siltstones were predominately red, with pale reddish-brown (10 R 5/4), moderate reddish-brown (10 R 4/6), and dark reddish-brown (10 R 3/4) being the prevalent shades. Some green and gray claystone and shale beds also were observed, but these colors were rare. All of the sandstones were light colored, generally white. No red sandstones were observed. Some black sandstones were noted. The black coloring was due to a coating of solid hydrocarbons on the sand grains.

Cementing materials of the claystones, shales, and siltstones included clay, limonite, hematite, dolomite, and calcite. Hematite and limonite were easily recognized by the red color they imparted to the rocks.

Three types of cements were encountered while examining the sandstones: quartz, which was developed as secondary overgrowths around sand grains; carbonate cements, including both ferroan calcite and ferroan dolomite; and iron sulfide, including both pyrite and marcasite. The carbonate and sulfide cements were generally associated with one another and were often observed as cementing materials in the same rock fragment.

Staining of thin sections revealed that the ratio of calcite to dolomite cements was approximately 1:1, and the cements had a high iron content. The carbonates were observed replacing both quartz and sulfide cements (Figure 6).

The anhedral iron-sulfide cements made it difficult to differentiate between pyrite and marcasite, but where euhedral forms were observed, cubic pyrite was the predominate form. Pyrite and marcasite were distributed randomly in relation to one another, generally occurring in the same well. The iron sulfide cements were observed replacing quartz and carbonate

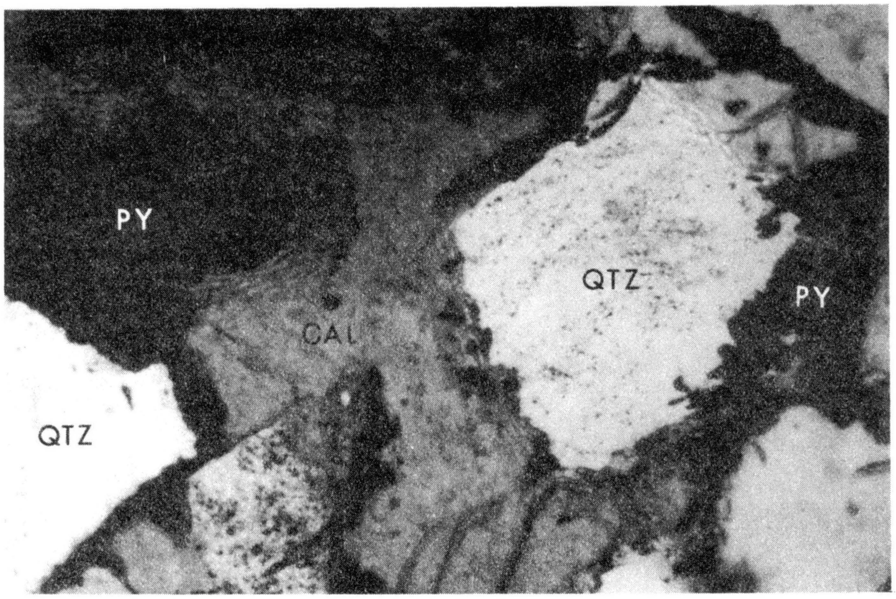

Figure 6. Photomicrograph of a Fine-Grained Sandstone Showing the Replacement of Quartz Grains by Pyrite and the Replacement of Pyrite by Calcite. (x160,.27x.40mm, crossed nichols)

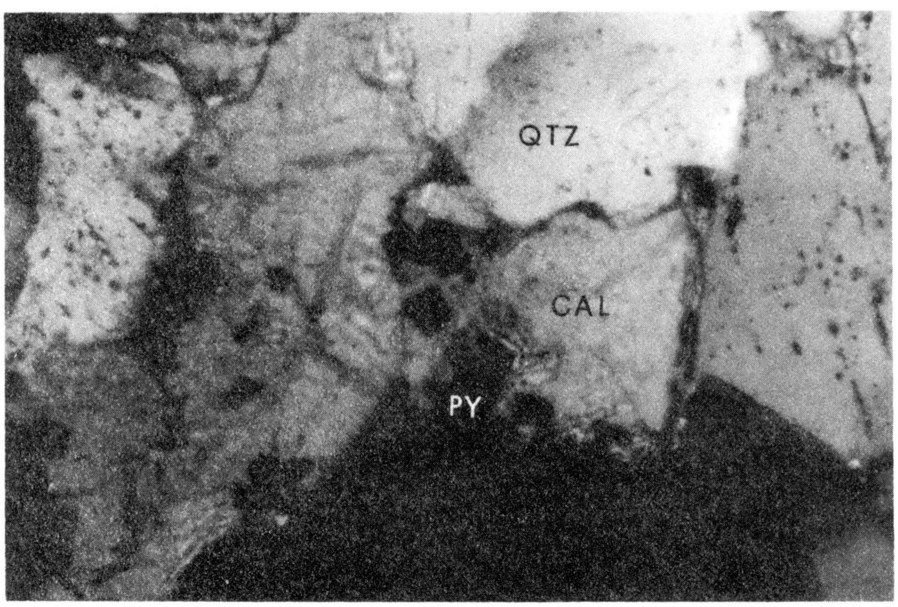

Figure 7. Photomicrograph of a Fine-Grained Sandstone Showing Euhedral Pyrite in a Calcite Matrix. (x160,.27x .40mm, crossed nichols)

cements (Figure 7). Pyrite was estimated to constitute up to 15% of the total rock in some cases, but this degree of development was unusual. Where present, pyrite generally averaged 3 to 4% of the total rock.

Pyrite cement is in 25 of the 40 wells surveyed. For the purposes of this study, a pyrite occurrence is defined as any well in which pyrite makes up at least 1% of the sandstone in the well. A zone was apparent after mapping pyrite occurrences in the field (Figure 8). The percentage of pyrite cement within this zone varies randomly both horizontally and vertically, but the boundary itself is sharp. This is shown by the wells defining the eastern edge of the boundary in sections 13, 24 and 25. An examination of the two wells on the eastern side of the boundary in section 13 and the southeastern quarter of section 24 revealed no pyrite in any of the sandstones, while the wells on the eastern side of the boundary in the northwest quarter of section 25 showed 2 to 3% pyrite cement throughout the sandstone intervals. The distance between the wells in which pyrite is developed and those in which it is not is 400 m. Other areas in which the sharpness of the boundary is emphasized include wells in section 9 and sections 15, 21 and 22. A cross-sectional view of the zone boundary is shown in Figure 5.

The pyrite cement zone is situated over the Permian production zone in its western half and overlies a part of the Springer production zone in its eastern half (Figure 9). The Springer zone lies approximately 450 m below the Permian-Pennsylvanian unconformity. The pyrite cement zone is

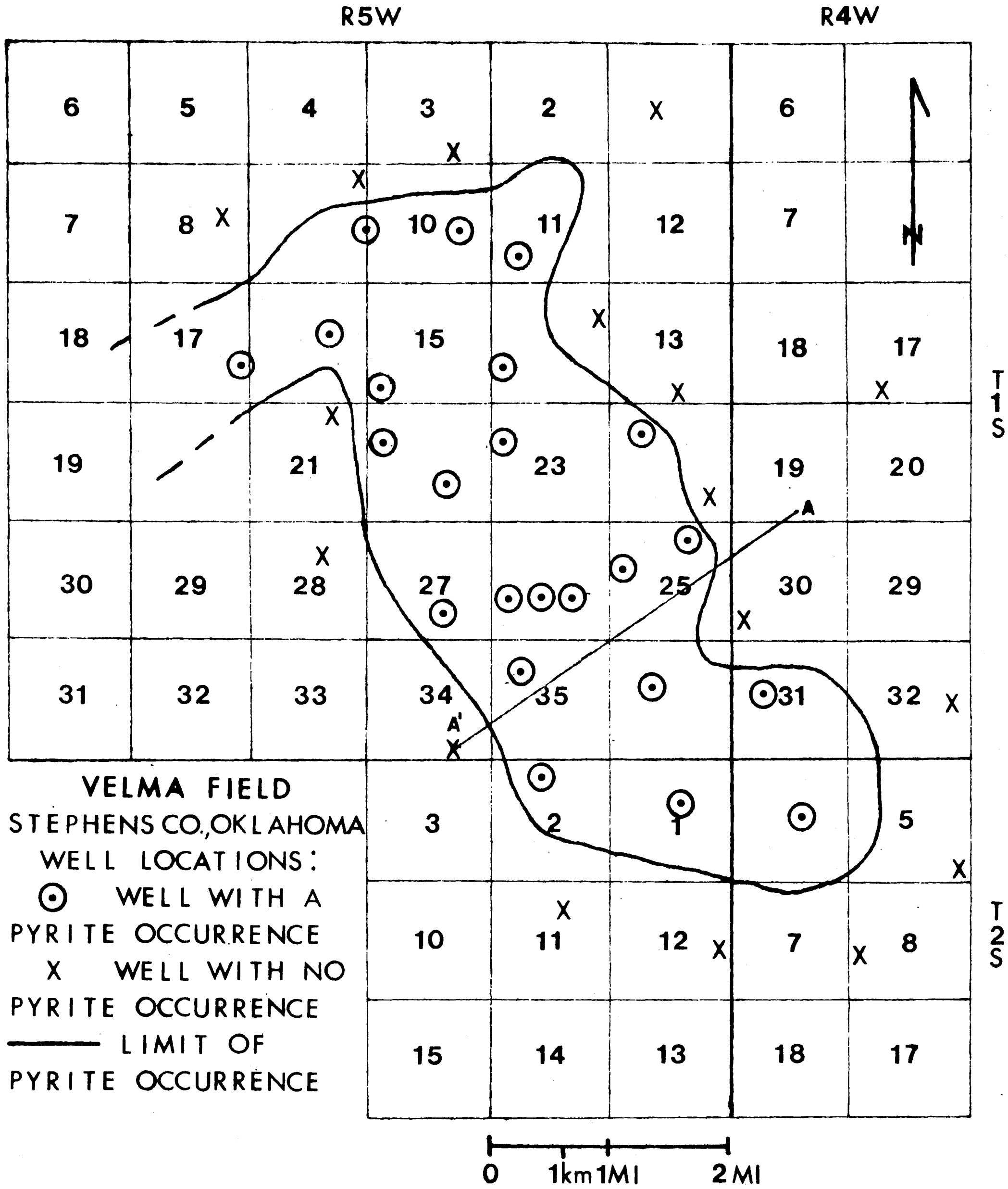

Figure 8. Well Location Map of the Velma Field, Showing Subsurface Pyrite Occurrences Defining the Pyrite Cement Zone

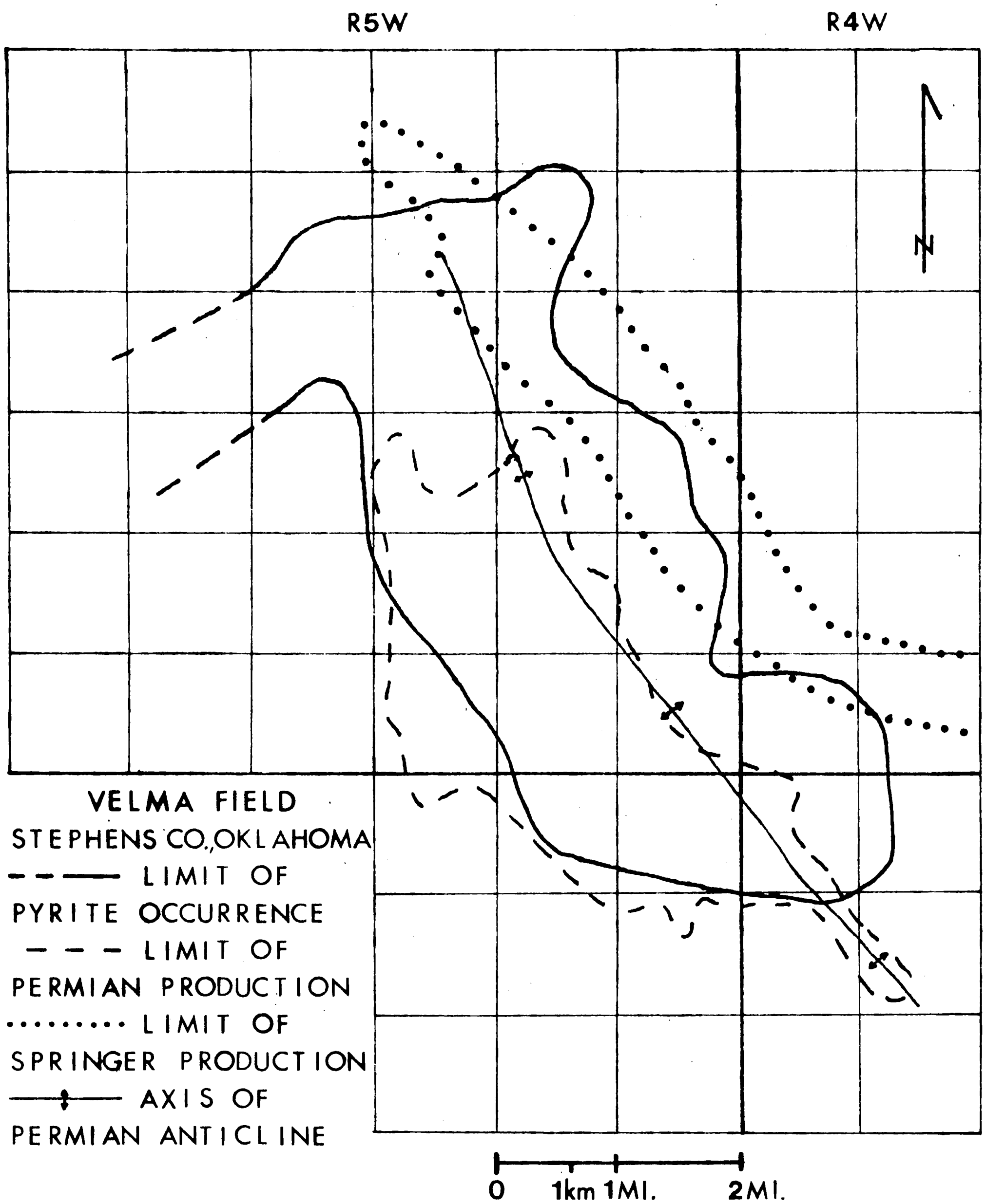

Figure 9. Map of the Velma Field, Comparing the Pyrite Cement Zone, Lateral Limits of Productive Areas, and the Permian Anticlinal Axis. Adapted from Rutledge (1955).

elongated along the structural trend and is fairly symmetrical about the anticlinal axis.

A comparison of the pyrite cement zone with a structure map of the field is shown in Figure 10. The zone overlies the area where faulting is the most extensive. The faults bounding the central horst run down the center of the zone and merge into one fault at the northern and southern boundaries of the zone.

The only minor constituents consistently observed within the Velma field were native sulfur and solid hydrocarbon residues. Sulfur was detected in 14 wells (Figure 11). The mineral was generally associated with pyrite and was found from depths of 10 to 300 m. Sulfur was present as coatings on sand grains. Solid hydrocarbons were present at places throughout the field and were found at the surface.

B. The Eola Field

(a) Structure and Stratigraphy

The Eola oil field is located in T.1N., R.2 and 3W., Garvin County, Oklahoma (Figure 1). The field is adjacent to the Arbuckle Mountains and is situated on the north flank of the Arbuckle anticline.

The area is characterized by a series of west north-west-trending complexly folded and faulted horsts and garbens (Figure 12). There are five major faults bounding these blocks, and the faults, from north to south, include: the

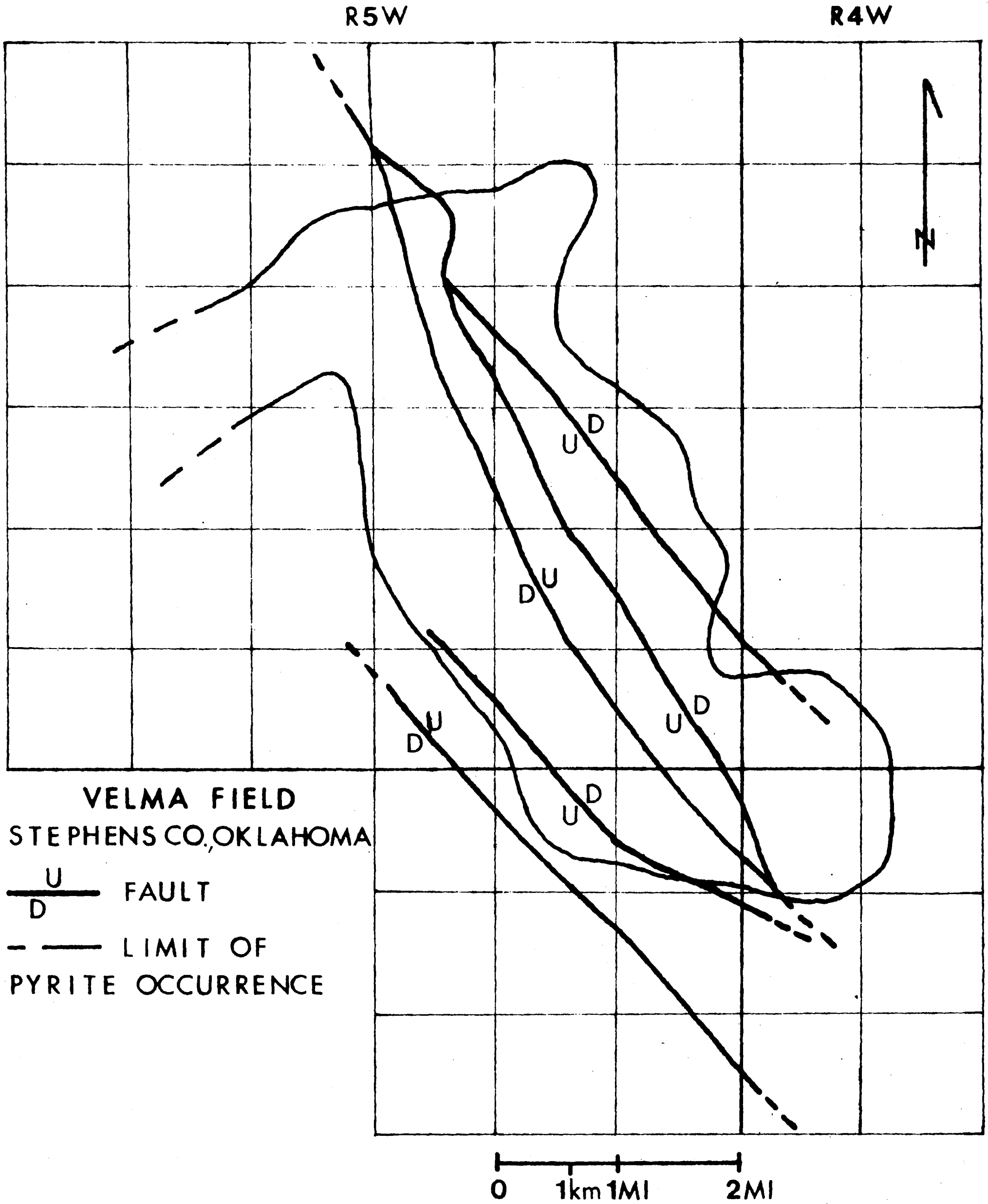

Figure 10. Map of the Velma Field, Comparing the Pyrite Cement Zone and Pre-Permian Faults. Adapted from Rutledge (1955)

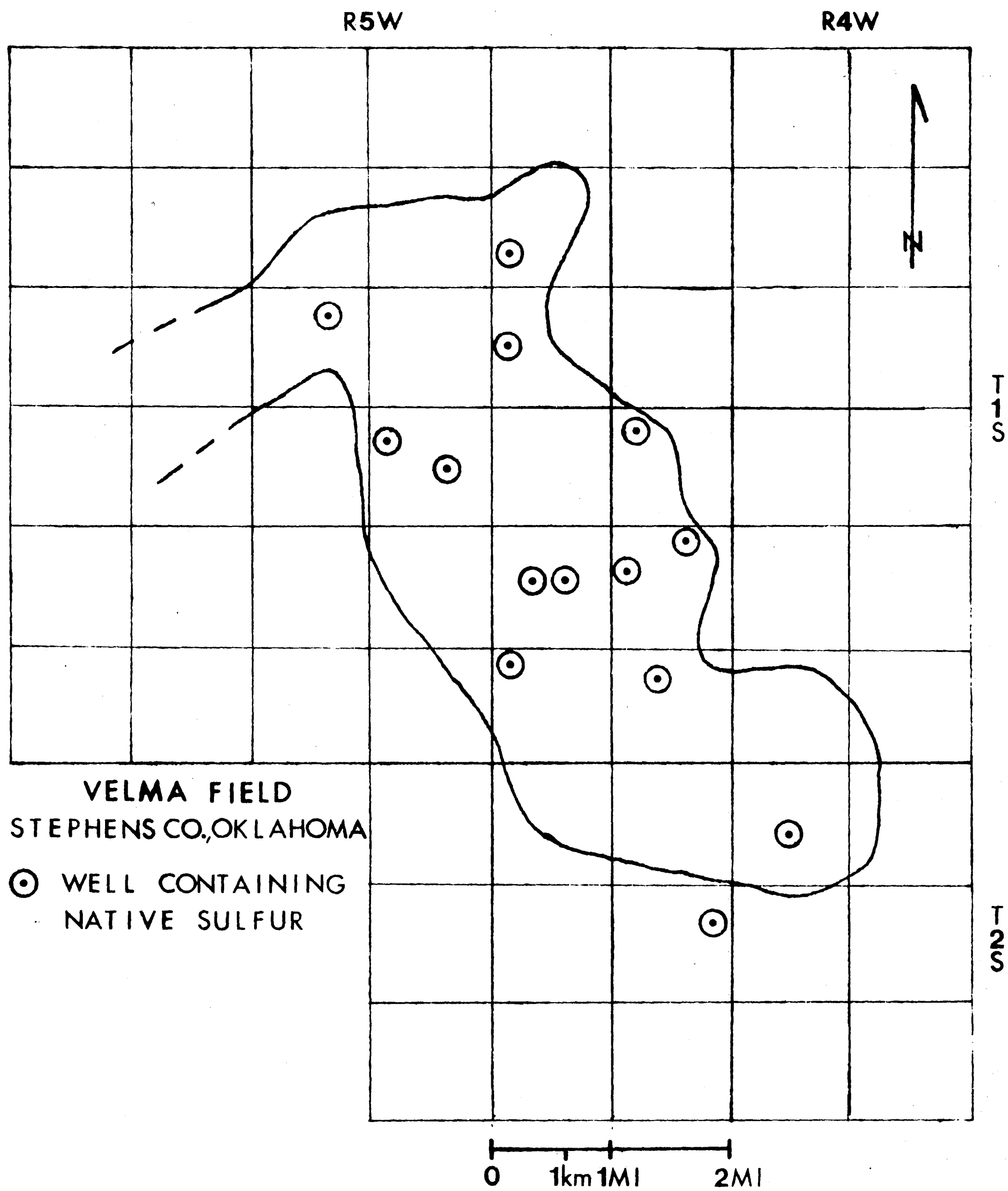

Figure 11. Map of the Velma Field, Showing Subsurface Native Sulfur Occurrences

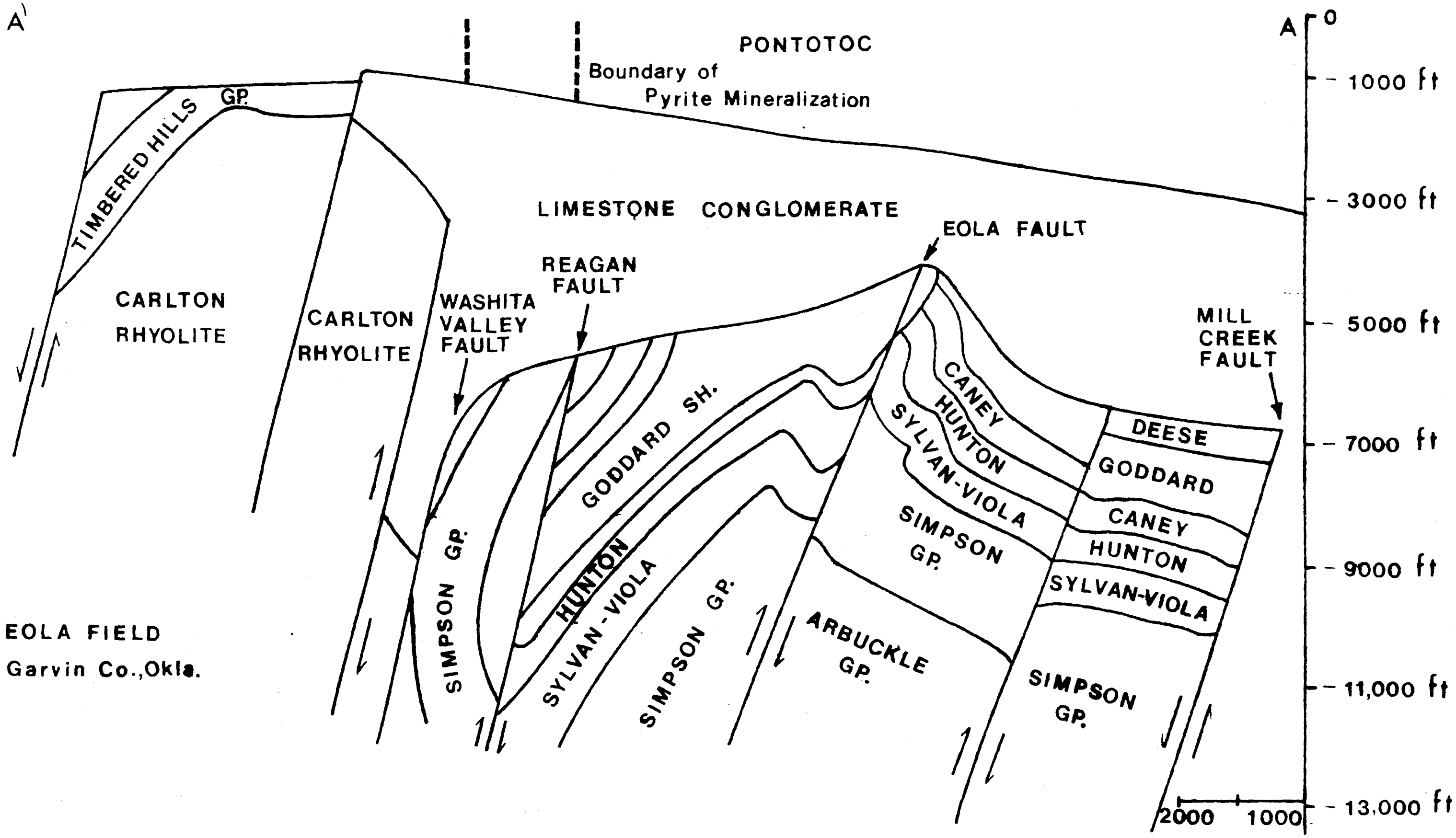

Figure 12. Cross Section of the Eola Field. From Harlton (1964)

Mill Creek fault, the Eola fault, the Reagan fault, the Washita Valley fault, and the Robberson fault. All but the Eola fault can be traced in the subsurface southeastward into the Arbuckle Mountains, where they are exposed at the surface. The faults are high-angle normal and reverse faults that show great variations in vertical displacement (Harlton, 1964). The faults are intersected by northeast-trending cross faults that divide the main blocks into many horsts, grabens, and tilted fault blocks. The major structure within the Eola field is an intricately faulted anticline, the south limb of which has been overturned by drag along the Reagan and Washita Valley faults forming an overturned syncline (Swesnik and Green, 1950).

Harlton (1964) believes that the lines of structural weakness along which the major faults of the area are located were developed during Cambrian time. Some orogenic activity did take place in the area during the Wichita orogeny, but this activity was minor compared to that of the Arbuckle orogeny. During this period of diastophism, the entire system of fault blocks was developed along a fracture zone which had undergone sporadic movement throughout Paleozoic time.

Producing zones within the Eola field include the Arbuckle Group of Ordovician age, the Simpson Group of Ordovician age, the Hunton Group of Devonian age, and limestone conglomerates of Pennsylvanian age. The Simpson Group is the most productive reservoir. Permian strata are not productive.

Rocks of the Permian System are those of the upper part of the Pontotoc Group. The group is not folded or faulted, and consists of red beds underlain by a 0-900 m thick sequence of limestone conglomerates. The age of the conglomerates is disputed as being either Pennsylvanian or Permian and the location of the Permian-Pennsylvanian boundary has not been resolved. The top of the limestone conglomerate sequence was picked as the boundary for this study.

(b) Lithology and Diagenetic Features

Bit cuttings from 35 wells in the Eola field were examined and logged. In 11 wells the sample interval began at the surface, and the Permian-Pennsylvanian boundary was encountered in 24 wells.

Permian rocks within the area are similar to those in the Velma field. Rock types include claystone, shale, siltstone, and sandstone. Claystone was the most abundant rock type, and siltstone was the least abundant. Sandstone averaged about 30% of the rock types encountered in all of the wells. Grain sizes within the sandstones ranged from fine to coarse (.125 - 1.00 mm) with fine-grained sandstone being the most common. Medium and coarse-grained sandstone was rare. All of the sandstones were quartz arenites.

In each instance, color of the claystone, shale, and siltstone was reddish brown. Sandstones were predominately white in color. A reddish brown sandstone was observed in one well, and black, pertoleum-coated sandstone fragments were common.

Cements included quartz, clay, limonite, hematite, ferroan calcite, ferroan dolomite, and pyrite. The clay and limonite cements were found only in mudstones, while the pyrite and quartz cements were restricted to sandstones. Ferroan calcite and dolomite cements were found in all rock types and were the predominate cements in the sandstones. The ratio of calcite to dolomite was generally 1:1. The carbonate cements were observed replacing quartz and iron sulfide cements (Figure 14). Quartz was developed as secondary overgrowths.

Pyrite was associated with the carbonate cements in 13 wells. It was euhedral and anhedral and was observed to replace quartz grains and carbonate cement (Figure 13). The average pyrite content of sandstone was 3%, but pyrite did comprise 50% of the total sandstone in one well.

As in the Velma field, pyrite cement is in a zone (Figure 15). The pyrite cement zone boundary in the Eola field was defined using the same criteria employed in the Velma field. The zone is irregular in shape and elongated along an east-west trend. It is 9.6 km in length and varies from .8 to 4 km in width. Pyrite percentages within the zone vary from 1 to 50% and do not show a regular distribution in either a horizontal or vertical direction. The closest spacing of a well showing pyrite cementation to a well displaying no pyrite cementation is one kilometer. These wells are located in sections 17 and 18 of T. 1N., R.3W. A cross-sectional view of the zone boundary is shown in Figure 12.

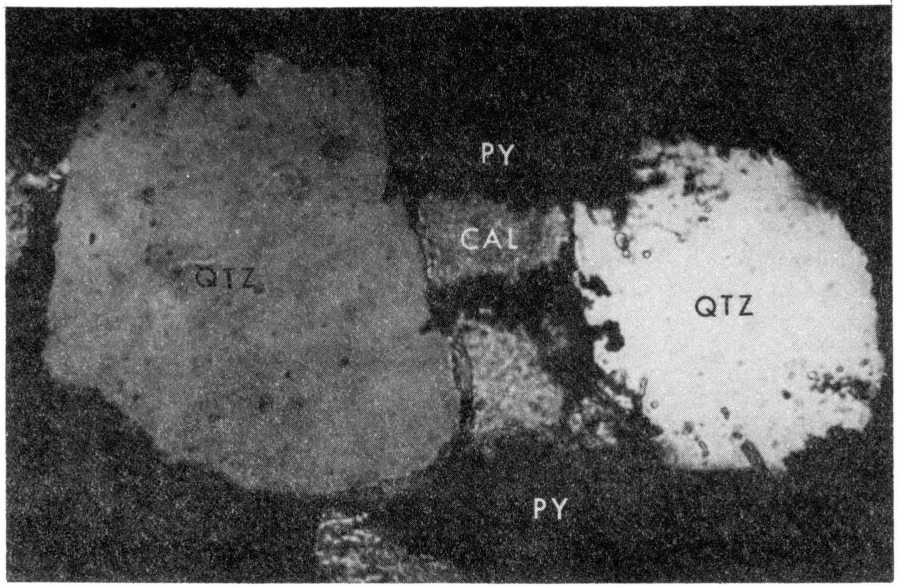

Figure 13. Photomicrograph of a Fine-Grained Sandstone Showing the Replacement of Quartz Grains and Calcite Cement by Pyrite. (x160,.27x.40mm, crossed nichols)

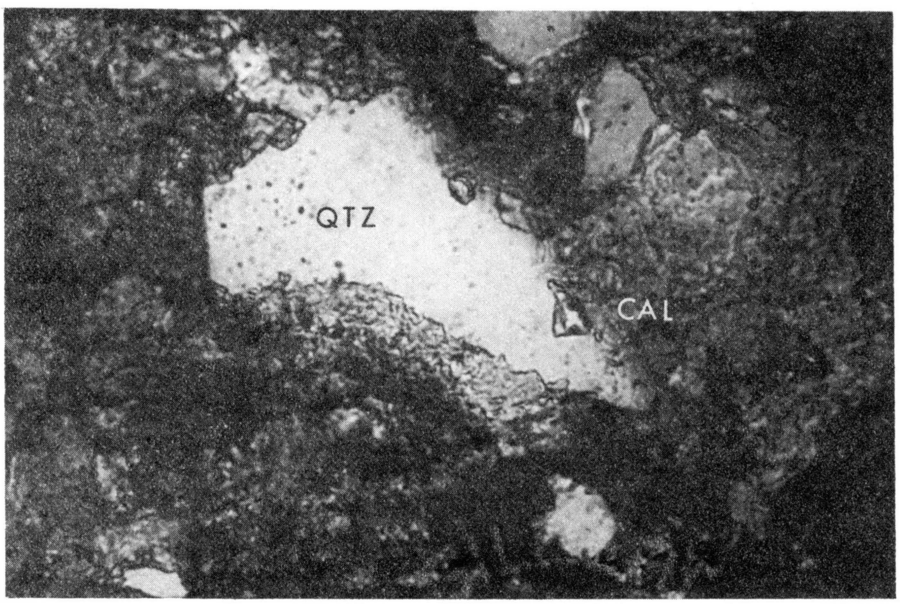

Figure 14. Photomicrograph of a Fine-Grained Sandstone Showing the Replacement of Quartz Grains by Calcite Cement. (x160,.27x.40mm, crossed nichols)

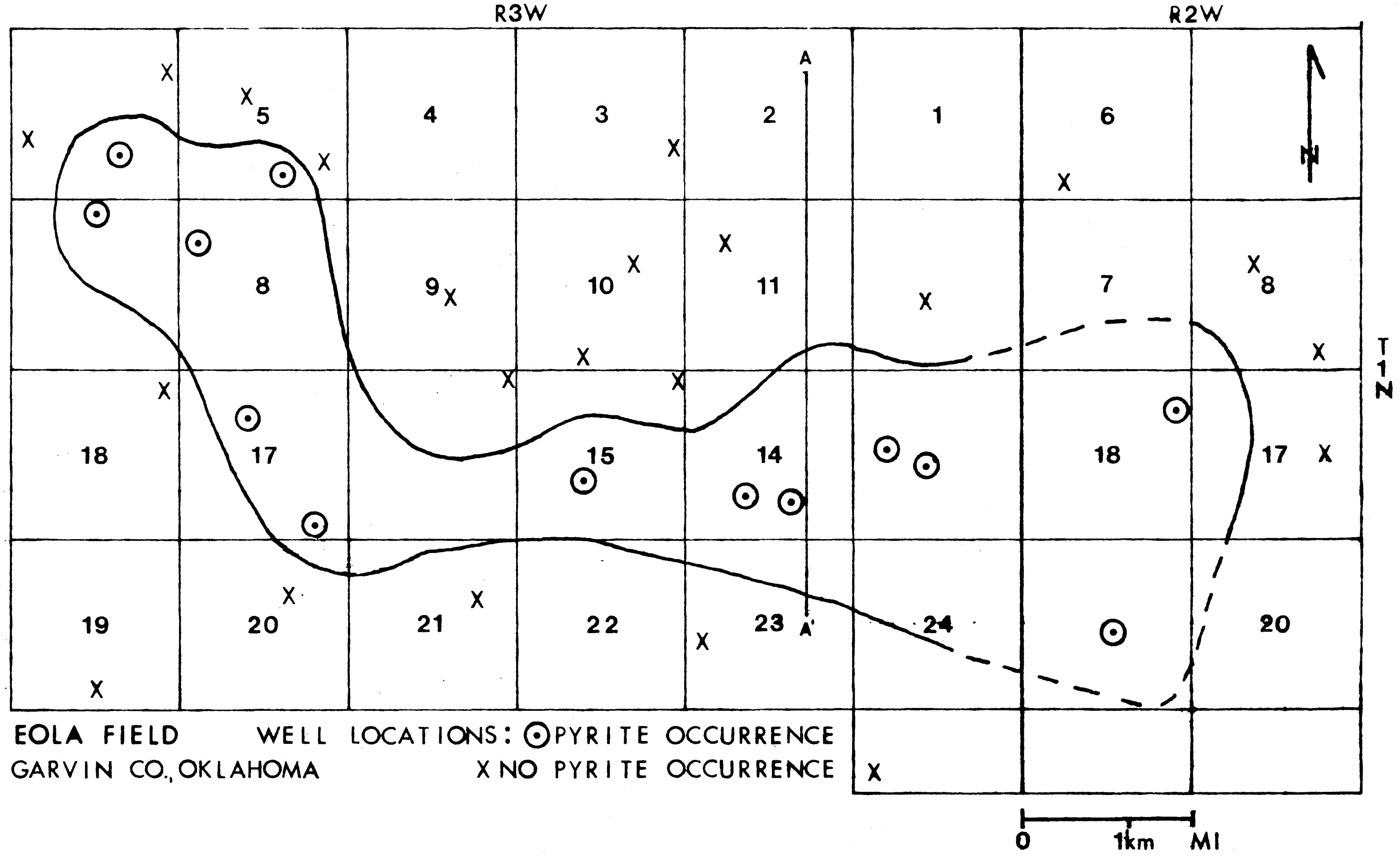

Figure 15. Well Location Map of the Eola Field, Showing Subsurface Pyrite Occurrences Defining the Pyrite Cement Zone

A comparison of the pyrite cement zone with the production zone of the Eola field is illustrated in Figure 16. The pyrite cement zone falls within the production zone over much of its extent. The zones are elongated in the same direction and are approximately the same length. The zone widths are comparable at their eastern and western extremities.

The Washita Valley fault is overlain by the pyrite cement zone along most of its length, and the zone is elongated along the structural trend (Figure 17).

Native sulfur was observed in only four wells within the field. It was developed at depths as shallow 58 m and as deep as 580 m. The mineral made up approximately 1% of an 85 m interval in section 17, T.1N., R.3W.

Solid hydrocarbon residues were occasionally recognized throughout the field, and were observed within 12 m of the surface.

C. The Chickasha Field

(a) Structure and Stratigraphy

The Chickasha oil field is located in T.5N, R.8W. and T.4N., R.8W., Grady County, Oklahoma (Figure 1). The field is situated on the periphery of the Anadarko basin and is a southeastern continuation of the Cement oil field in Caddo County. The stratigraphy and structural development of the two fields are closely related.

The Chickasha structure is a north-northwest - trending anticline which is broken on its eastern flank by a high-

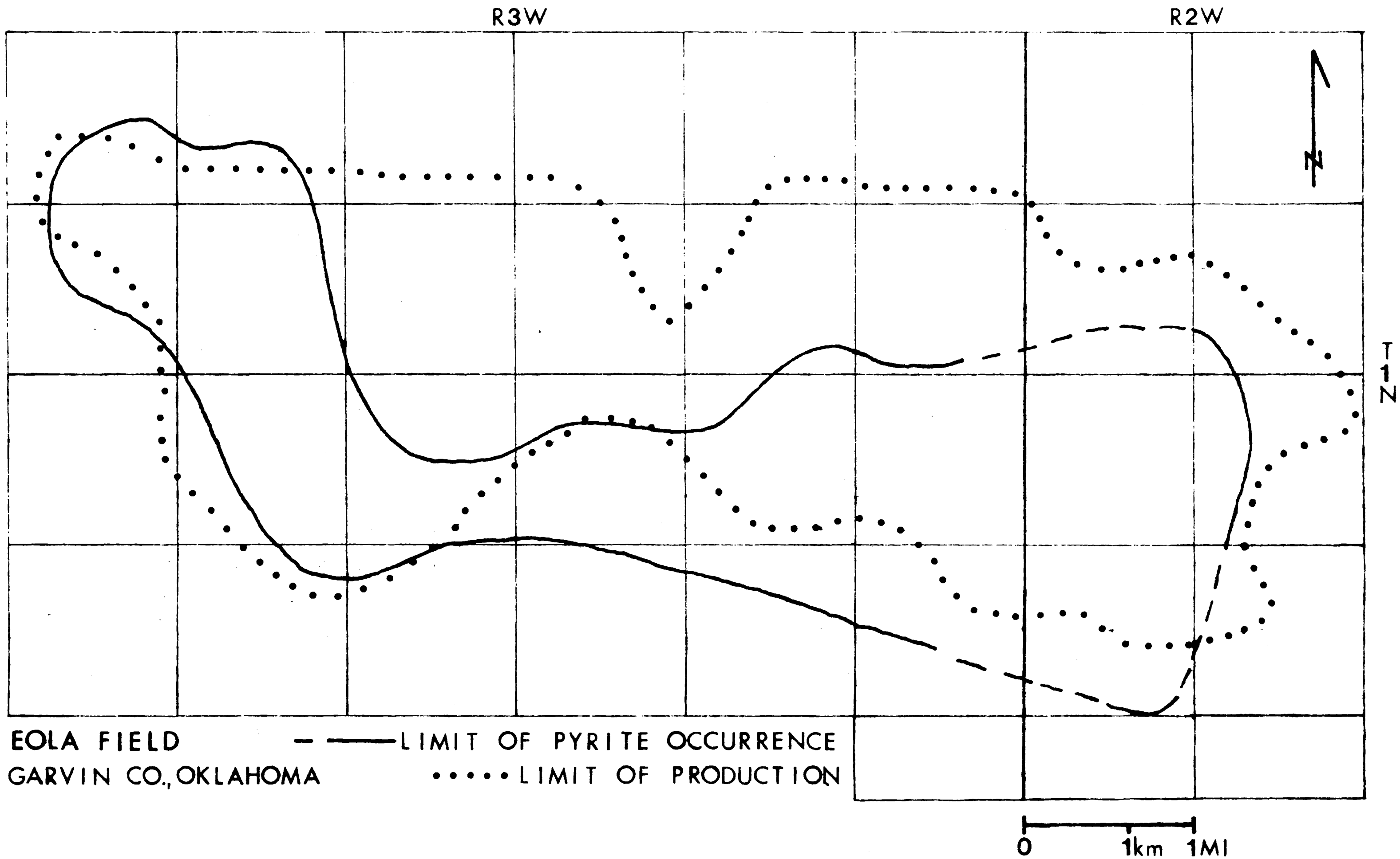

Figure 16. Map of the Eola Field, Comparing the Pyrite Cement Zone and the Lateral Limits of Production

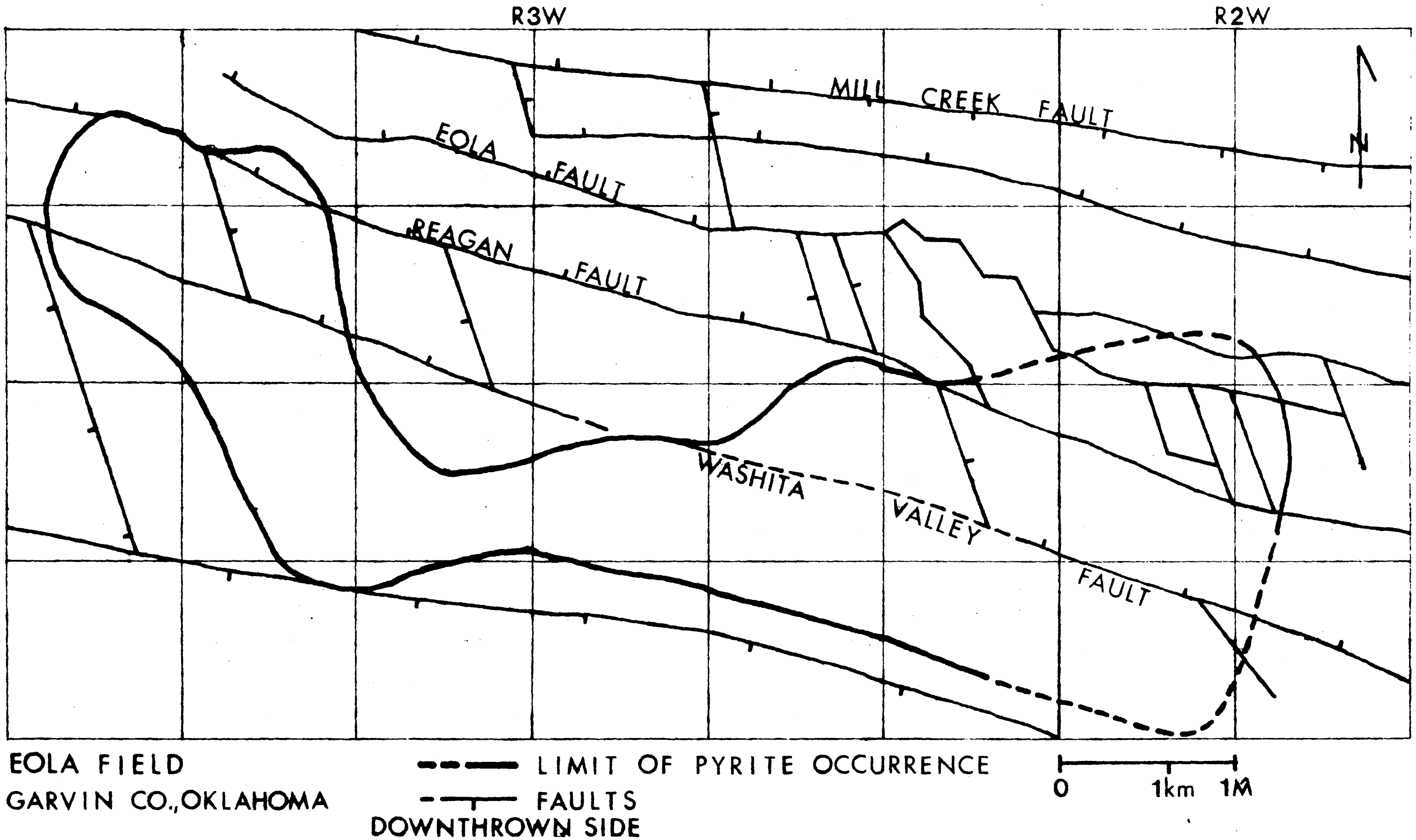

Figure 17. Map of the Eola Field, Comparing the Pyrite Cement Zone and Pre-Permian Faults

angle reverse fault showing several thousand meters of displacement (Herrmann, 1961). This fault is believed to become a thrust fault at depth (Figure 18).

Structural development of the Chickasha area took place during the Morrowan, Atokan, Missourian, and Virgilian epochs along more ancient lines of structural weakness (Harlton, 1960). Movement along the major reverse fault began in Atokan time and continued until Wolfcampian time. The greatest structural deformation took place in Missourian and Virgilian time (Herrmann, 1961). Most of the structural activity was associated with the Wichita orogeny. The faults affecting Pennsylvanian strata do not continue upward into Wolfcampian units, but these units are folded where they overlie the major faults. The degree of folding diminishes upward through the Permian section, but anticlinal folds in Leonardian formations are mappable at the surface.

Almost all of the production of oil and gas within the Chickasha field is from reservoirs within Permian formations. Sandstones showing continuous lateral development are the producing horizons. The upper part of the Pontotoc Group makes up the Wolfcampian Series. The Leonardian Series is comprised of the Rush Springs, Chickasha, Duncan, Hennessey, and Garber formations (Figure 19). The Guadalupian Series is represented by the Cloud Chief Formation which is found in the Cement area. The average thickness of the Permian section , and truncated Pennsylvanian units lie below this erosional surface.

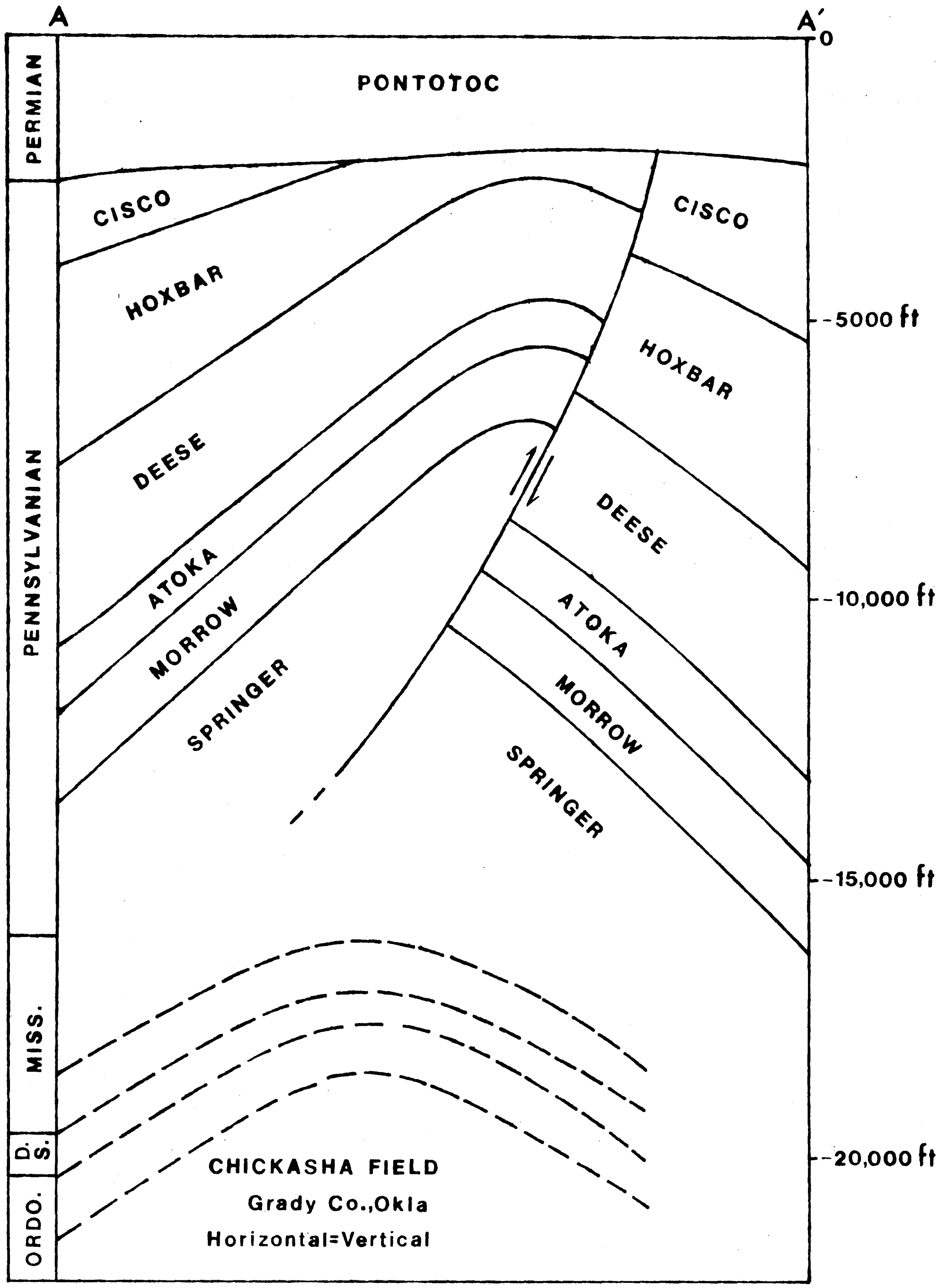

Figure 18. Cross Section of the Chickasha Field. After Herrmann (1961).

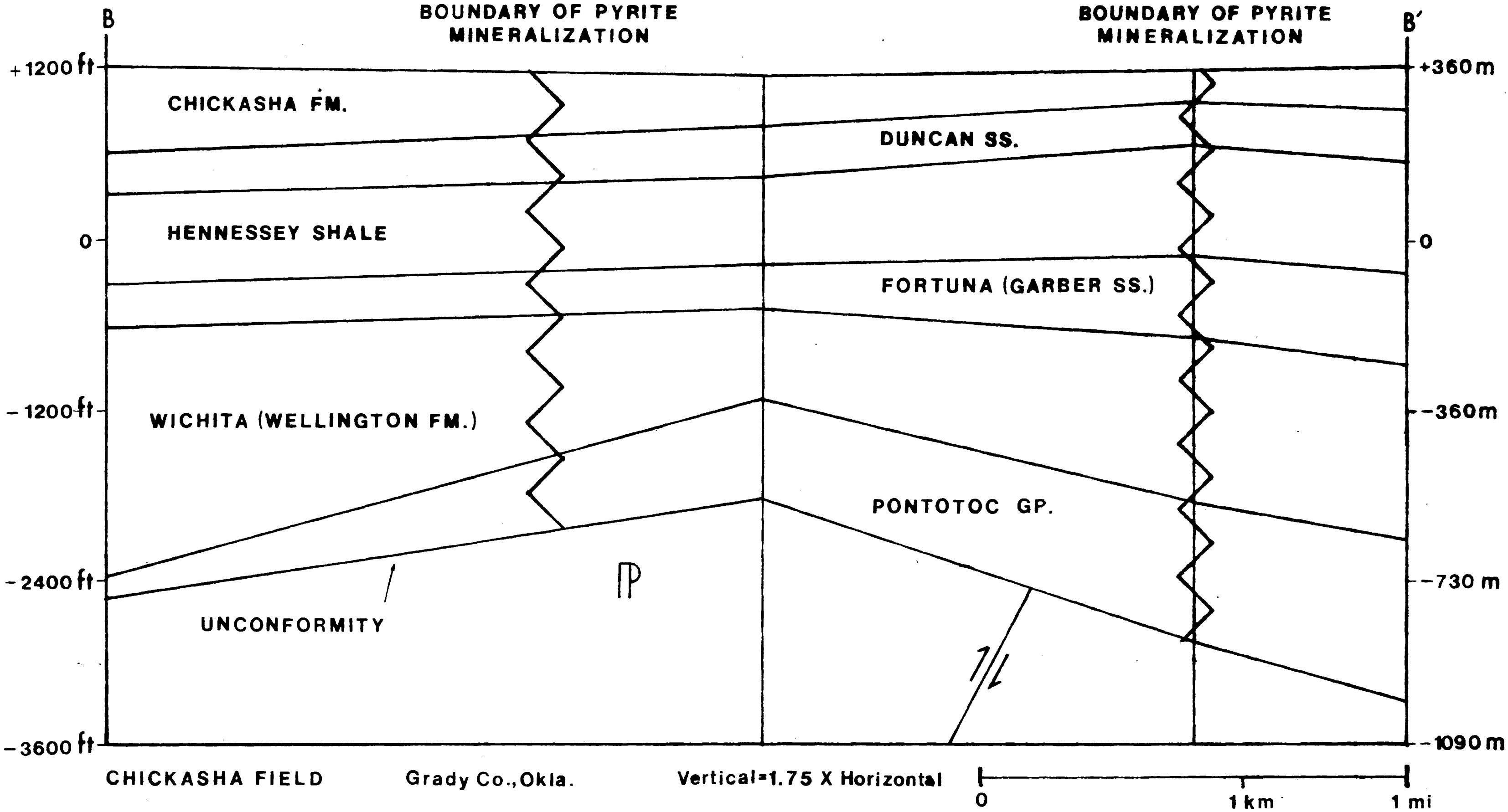

Figure 19. Cross Section of the Chickasha Field, Showing Permian Units and the Boundary of the Pyrite Cement Zone.

(b) Lithology and Diagenetic Features

Cuttings from 29 wells within the Chickasha field were examined. Only two wells had sample intervals beginning at the surface, and the Permian-Pennsylvanian contact was encountered in 15 wells. This contact was marked by the appearance of limestone and black shale fragments.

Rock types observed include claystone, silty shale, siltstone, and sandstone. Silty shale and siltstone were the most often encountered lithologies. These two rock types combined made up approximately 60% of the rocks within the section studied. Claystone was observed infrequently. Very fine-grained sandstone made up 30-40% of the total rock types within most wells.

All of the claystone, silty shale, and siltstone were various shades of red with moderate reddish brown (10 R 4/6) being the predominant shade. All of the sandstones were white.

Cements included clay, limonite, hematite, ferroan calcite, ferroan dolomite, and pyrite. Clay, limonite, and hematite were restricted to the mudstones, while pyrite cement was observed only in sandstones. Pyrite was observed replacing carbonate cement (Figure 20) and quartz grains (Figure 21). Ferroan calcite and dolomite cements were ubiquitous and present in roughly equal proportions. Limonite and hematite cements were responsible for the red coloration in the finer grained rocks.

Pyrite was observed in 17 of the wells described. The pyrite cements occurred within a zone, but the zone boundary

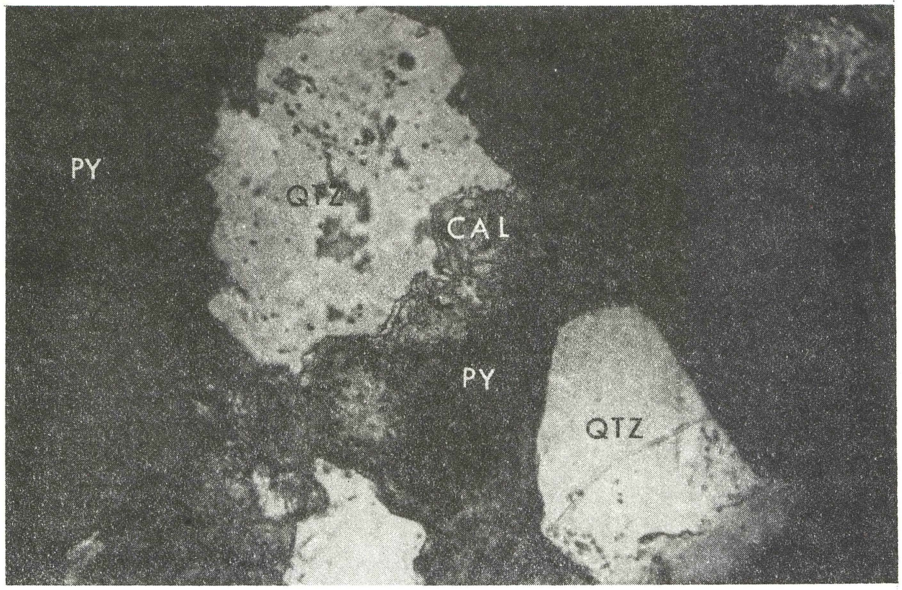

Figure 20. Photomicrograph of a Fine-Grained Sandstone Showing the Replacement of Quartz Grains by Pyrite and Calcite and the Replacement of Calcite by Pyrite. (x160,.27x .40mm, crossed nichols)

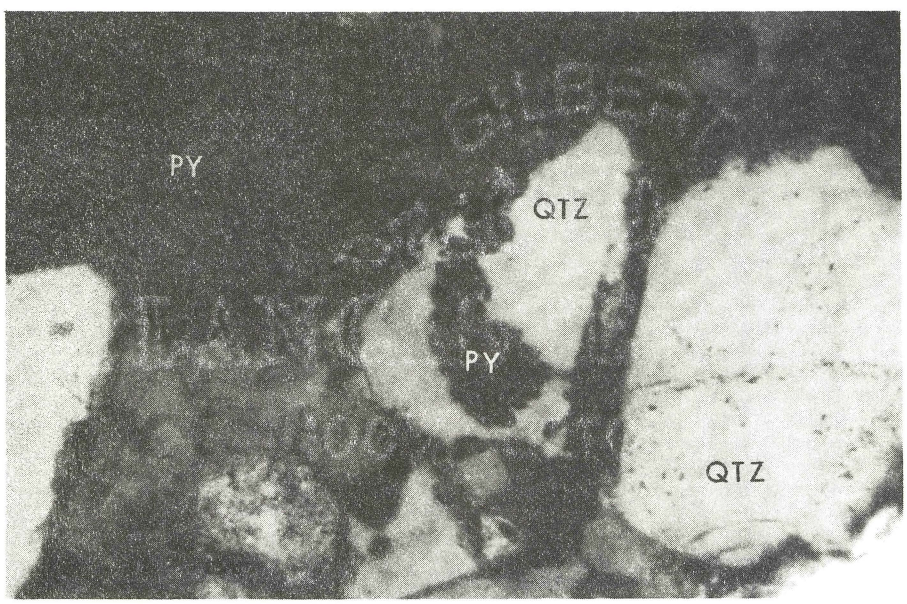

Figure 21. Photomicrograph of a Fine-Grained Sandstone Showing the Replacement of Quartz Grains by Pyrite. (x160,.27x.40mm, crossed nichols)

was not as well defined as in the other fields (Figure 22). The zone is arcuate in shape and approximately 8 km long and 2 km wide. The maximum amount of pyrite cement recorded within the sandstone intervals was 5%, and the average amount was 2%.

The pyrite cement zone is contained within the productive area of the field (Figure 23). The two zones are elongated in the same direction and have roughly the same shape. The pyrite cement zone ends at the southern boundary of T.5N., R.5W., while the production zone continues southward.

The pyrite cement zone is elongated along the structural trend (Figure 24), and the bending of the zone is coincident with the change in structural trend from west northwest to north northwest. The zone is located over the crest of the Pennsylvanian anticline (Figure 24).

The only minor constituent observed within the field was gypsum. Its development was restricted to Leonardian and Guadalupian mudstones and comprised up to 10% of the rock fragments in some wells.

D. The Altus Field

(a) Structure and Stratigraphy

The Altus oil field is located in T.1N., R.20W., Jackson County, Oklahoma (Figure 1). It is situated within the Hollis basin south of the Wichita Mountains and overlies a northwest-southwest trending structural high of mafic and silicic igneous rocks.

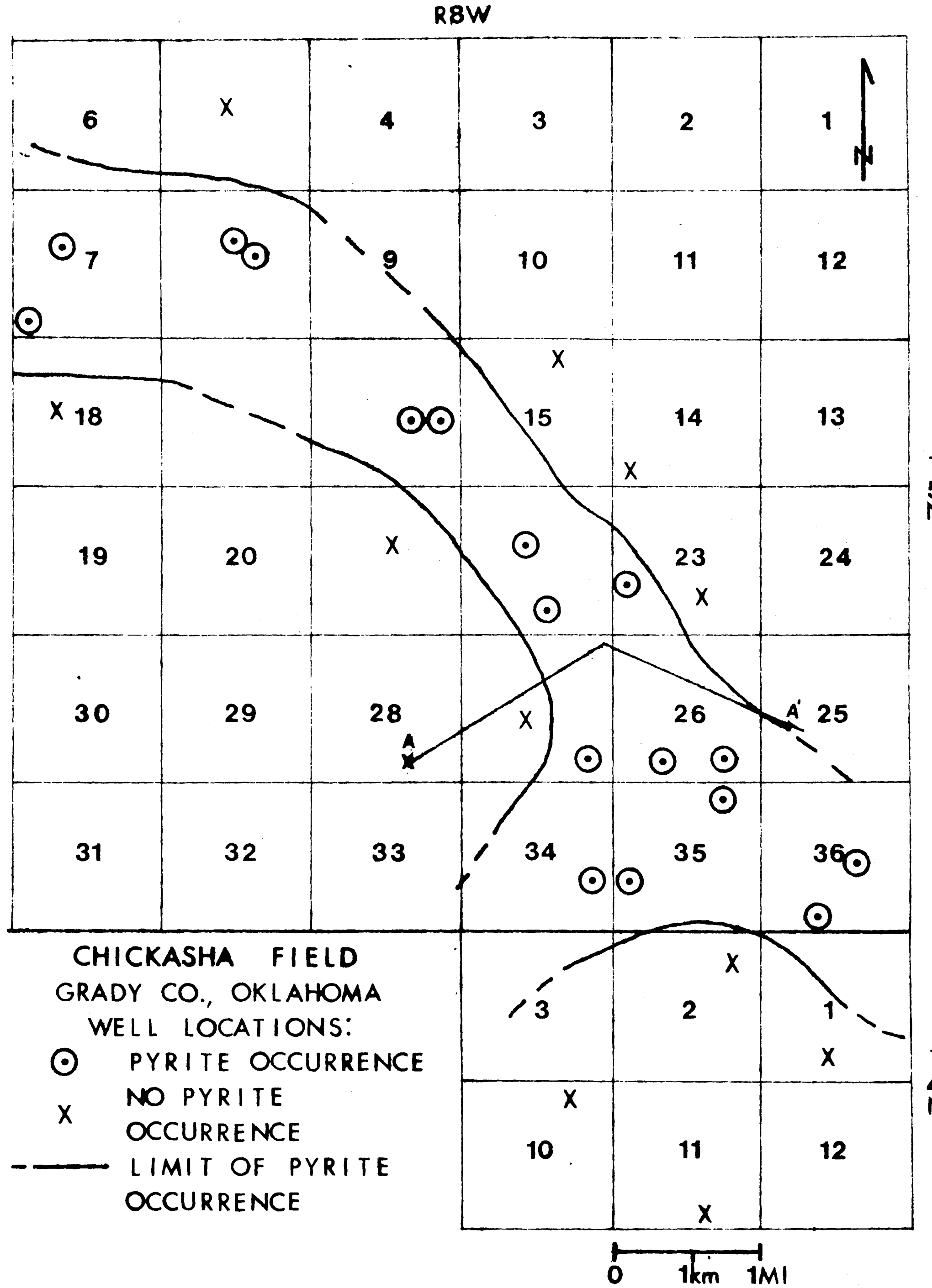

Figure 22. Well Location Map of the Chickasha Field, Showing Subsurface Pyrite Occurrences Defining the Pyrite Cement Zone

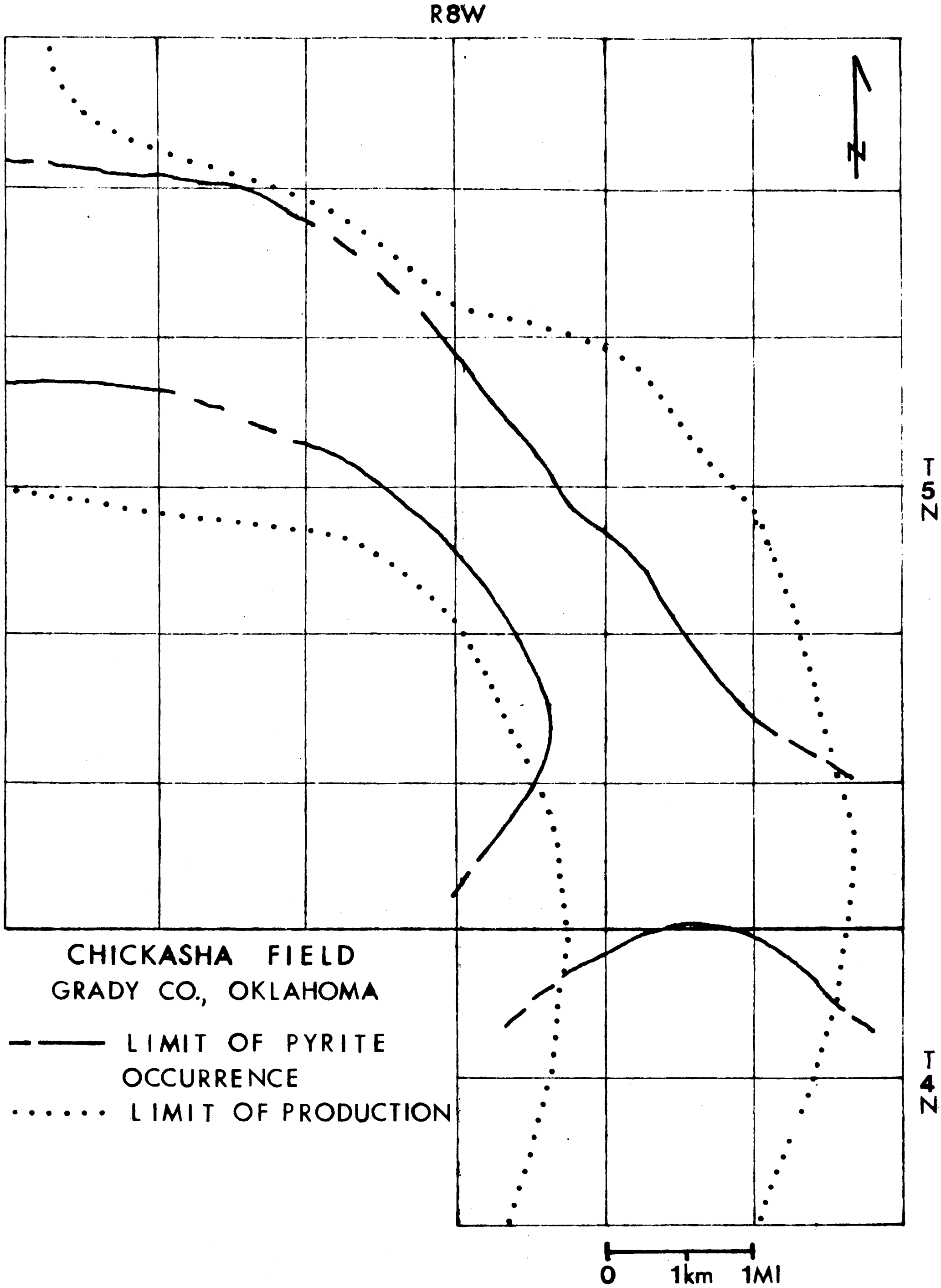

Figure 23. Map of the Chickasha Field, Comparing the Pyrite Cement Zone and the Lateral Limits of Production

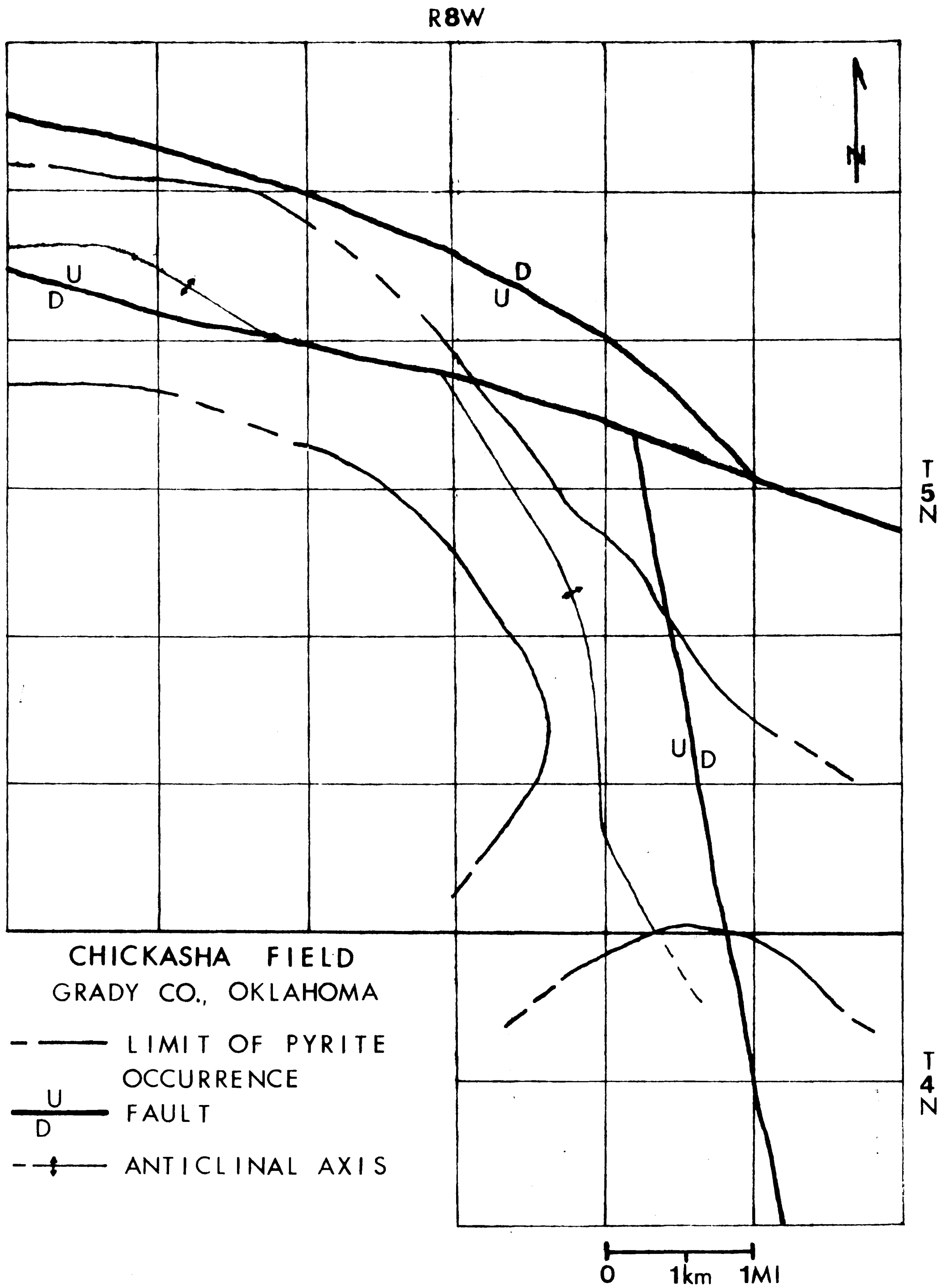

Figure 24. Map of the Chickasha Field, Comparing the Pyrite Cement Zone and the Pre-Permian Structures. After Ryniker and others (1959).

The structure forming the oil field is a north-south trending anticline which is bordered on its eastern flank by a normal fault with approximately 120 m of displacement (Figure 25).

The formation of the anticlinal fold was the result of diastrophic events culminating with the Wichita orogeny during late Morrowan time. The igneous mass was thrust upward during this orogeny and all sedimentary rocks were eroded from the block. This block was periodically uplifted until Leonardian time (Ryniker and others, 1959). Rocks deposited over the block range from Virgilian to Leonardian in age.

Permian units within the field include the Pontotoc Group of Wolfcampian age and the Wellington and Hennessey formations of the Leonardian Series. Reservoirs are all found within the Pontotoc Group and consist of a series of arkoses commonly referred to as "granite wash". The Wichita Mountains were the source of the arkosic material which are present throughout the southwestern part of the state.

(b) Lithology and Diagenetic Features

An examination of well cuttings throughout the field revealed a predominance of two lithologies. The upper 400 m of Permian strata are siltstone, while the rest of the section (150-250 m) is clayey, arkosic sandstones. These arkosic sandstones are made up of quartz, feldspar and basalt grains

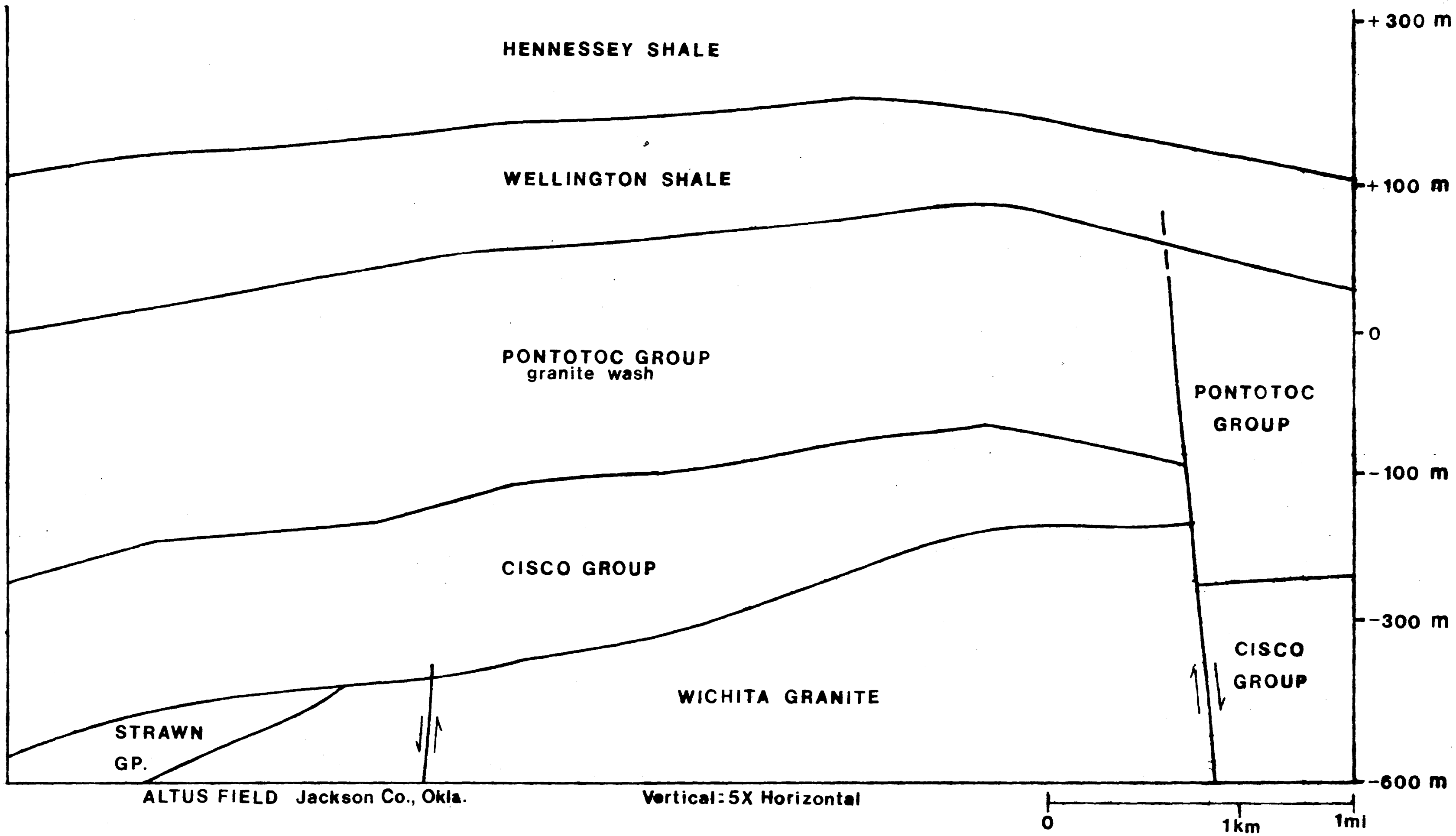

Figure 25. Cross Section of the Altus Field. From Ryniker and others (1959).

imbedded in a clay matrix. They are very poorly sorted with grain sizes ranging from very fine to coarse (.031-2.00 mm).

The siltstones always were various shades of reddish brown. The color of the arkosic rocks was largely dependent upon the color of the clay which made up the matrix. Grayish red (10 R 4/2) was the most common color. A few sandstones without a clay matrix were encountered and, without exception, were reddish brown.

Cementing materials were clay, limonite, hematite, dolomite, and calcite. Clay containing minor amounts of limonite, hematite, calcite, and dolomite were prevalent cements in the arkoses, while calcite, dolomite, limonite, and hematite were found in the siltstones. No mineral zonations were discernable. Minor constituents were gypsum and salt.

Although the Altus field does produce from a sequence of Permian strata, it differs from the three fields previously described in several respects. The field contains a series of clayey, arkosic sandstones not present in the other fields. X-ray diffraction techniques indicate that the clay within the sandstones is chlorite. The clay matrix apparently formed from the decomposition of basalt fragments within the rock, and this authigenic clay has severely decreased permeability within the sandstones. The structure of the field consists of only minor anticlinal folding and faulting. The sandstone intervals are red and no pyrite cement zone exists. Another important difference is that no Pennsylvanian formations are truncated beneath the Permian strata at the crest of the anticline. An explanation of the differences in coloration and cementation between the Altus field and the Velma, Eola, and Chickasha fields will be developed in the chapters to follow.

Summary

It is apparent from the previous descriptions that the Velma, Eola, and Chickasha oil fields are very similar in terms of stratigraphy, structure, and petrology. All of the fields are stiuated on the flanks of the Anadarko basin. The Permian System is represented by a series of red beds composed of claystone, shale, siltstone, and sandstone. The major structures are broad anticlinal folds affecting all Palezoic formations. They are broken by one or more high-angle normal and reverse faults showing several hundred meters of displacement. All of the sandstones in the fields are white, having carbonate and pyrite cements. The pyrite cement occurs in a zone located over the crests of the major anticlines and also overlies oil productive zones and pre-Permian faults.

These three fields also have many features in common with the Cement oil field in Caddo County. The stratigraphy and structure of the Cement and Chickasha areas are almost identical (Herrmann, 1961). Donovan (1972) noted that all the sandstones in the Cement area were white and had carbonate cements, while all of the finer grained rocks were red. This division of white sandstones and reddish mudstones was recognizable on the surface as well as in the subsurface. The author was able to establish a correlation between carbonate cementation in sandstones and productive areas at depth.

Donovan (1972) does not report pyrite in the Cement field. However, Donovan's study was directed towards a description of the rocks at the surface and his examination of subsurface alteration was limited. Pyrite mineralization would not be recognized at the surface due to the rapid oxidation of the mineral to hematite. The pyrite cement zone described in the Chickasha field borders the Cement area and is not closed along this border in sections 6, 7, and 18, T.5N., R.8W. It is likely that the zone extends into the field.

CHAPTER IV

GEOCHEMISTRY AND DIAGENESIS

The change in cementing materials within Permian sandstones from the usual association of limonite, hematite, and carbonates (see Chapter II) to an association of pyrite and carbonates near oil-productive structures poses an intriguing geochemical problem. A mechanism must be established that explains the diagenesis of cementing materials and the association of the secondary cements with structural highs containing hydrocarbon accumulations.

The most striking change associated with the development of altered sandstones is the total absence of red, iron oxide cement within the sandstone intervals. A review of the important aspects of iron geochemistry would be a logical place to begin an explanation of this observation.

Iron occurs as two different ions in nature, the ferrous ion with a valence of +2 and the ferric ion with a valence of +3. A stability field diagram for the ferrous-ferric system is shown in Figure 26. If the redox potential (Eh) and pH of the formation waters lie within the field of $Fe(OH)_3$, iron hydroxide will precipitate from the water and, upon dehydration, form a red iron oxide stain or cement within the rocks.

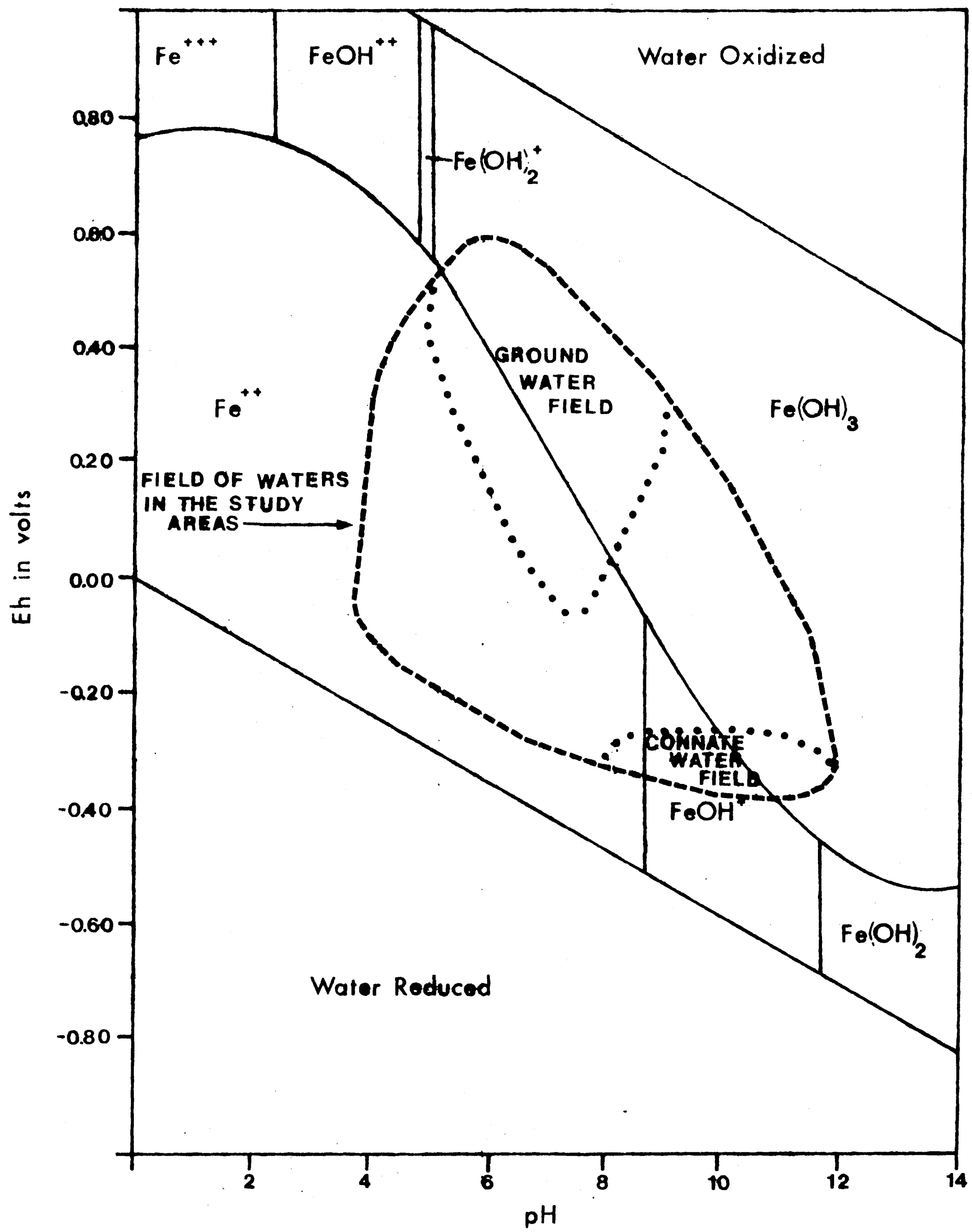

Figure 26. Stability Field Diagram for the Ferric-Ferrous System. From Hem and Cropper (1959). Ground Water Field from Baas Becking and others. (1960). Connate Water Field from Collins (1969).

If the Eh and pH of the formation waters lie within the field of ferrous iron, iron will stay in solution and be carried away.

A similar diagram showing the stability fields of the common iron minerals is shown in Figure 27. Pyrite (FeS_2) can only form in conditions more reducing (lower Eh) than hematite (Fe_2O_3). The presence of carbonate cement es-ablishes a minimum pH of 8.3 (Krauskopf, 1967). In order to convert hematite to pyrite at this pH, the redox potential of the formation waters must range from -0.2 to -0.35 volts. Thus, conditions favoring the development of the minerals cementing the sandstones in the study areas must not only be more reducing than those in adjoining areas, but also more reducing than in the adjacent mudstone.

The Eh of oil-productive areas is generally reducing (Collins, 1975). In a survey of Anadarko basin oil field brines, Collins (1969) measured redox potentials ranging from -.27 to -.30 volts. Conditions are favorable for the conversion of iron from the ferric to ferrous state and the formation of pyrite at the expense of hematite near petroleum-producing areas. The dissolution of ferrous iron in these localized reducing environments is responsible for the observed bleaching of red beds on the flanks of anticlines in southern Oklahoma. Birdseye (1957) and Kerr (1958) have also reported the bleaching of sandstone near petroleum reservoirs on the Colorado Plateau.

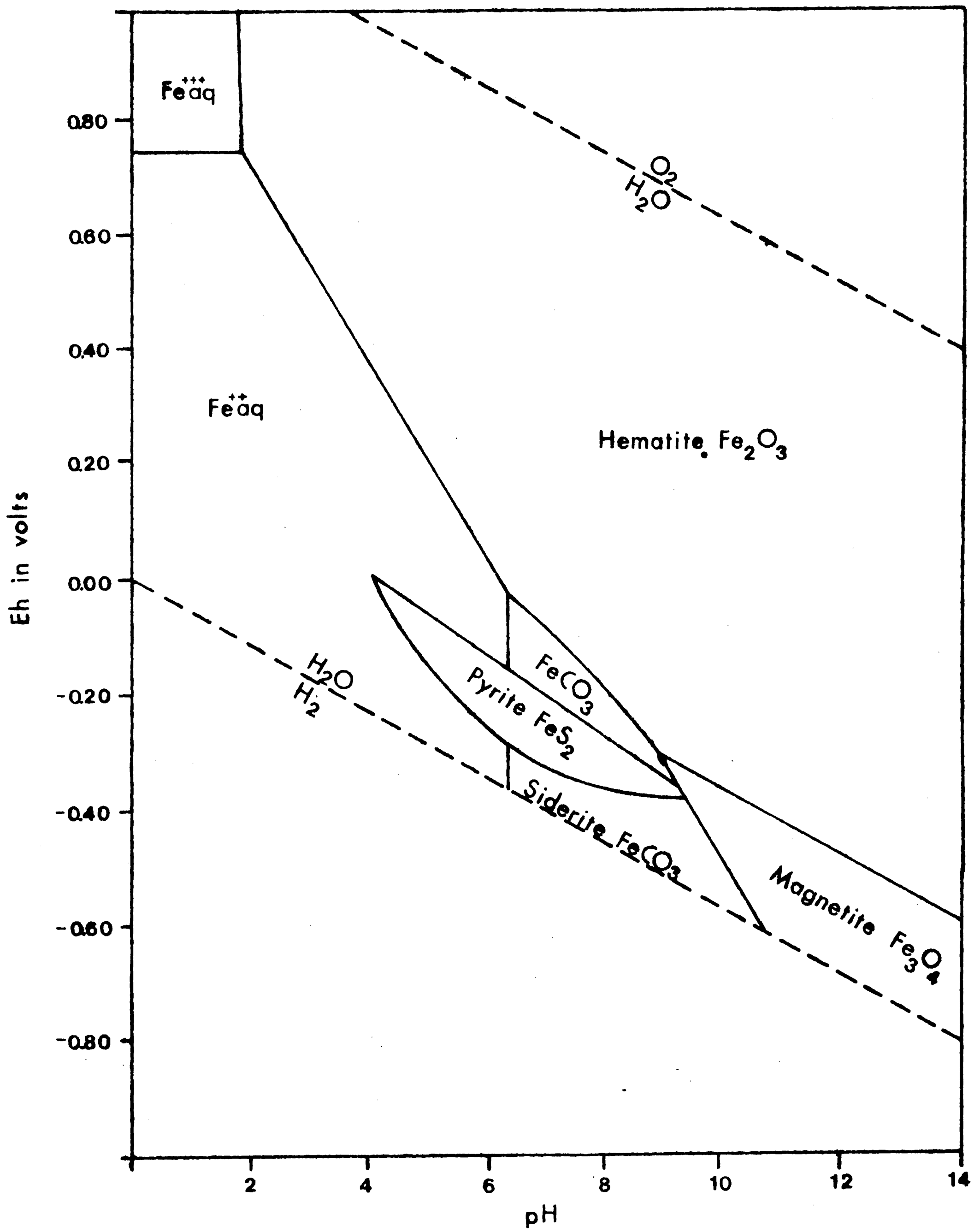

Figure 27. Stability Field Diagram for Iron Minerals. From Garrels and Christ (1965)

The process by which hydrocarbons create a reducing environment is poorly understood, and the statement that their presence causes reducing conditions is an oversimplification. Moulton (1926) found that the presence of hydrocarbons did not reduce iron oxides until a temperature was reached that destroyed the structure of the hydrocarbons, but that hydrogen sulfide gas (H_2S) associated with the petroleum could reduce iron oxide at surface temperatures and pressures. It is difficult to extrapolate the results of this experiment to encompass periods of geologic time, but it can be concluded that hydrogen sulfide is a more effective reductant than petroleum itself. The role of hydrogen sulfide gas as a reductant in the study areas is attractive, because it could also be the source of the sulfur necessary for the formation of pyrite. Having the reductant in gaseous or aqueous forms would also help explain the bleaching of sandstone intervals that show little evidence of having contained liquid petroleum. Donovan (1972) used hydrogen sulfide to explain the bleaching to red beds in the Cement area.

Published data pertaining to hydrogen sulfide content of the oils produced in the study areas is sparse. Rutledge (1955) reports the odor of the oil produced from the Velma field as poor, bad, and fair. It is hydrogen sulfide gas that imparts an unpleasant odor to petroleum. All of the oils produced from shallow reservoirs at Velma also are high sulfur oils with weight percent values ranging from 1.34 to 1.02%. Data from the other study areas are not available, but oil production in the other fields is from the same formations. Their compositions should be similar.

Hydrogen sulfide usually is found in oil-bearing strata, in which it usually appears as a result of the reduction of sulfates (Kartsev and others, 1959). Hydrogen sulfide in petroleum reservoirs may have several sources. The reduction of sulfate by anerobic bacteria to form hydrogen sulfide in recent sediments is well documented (Berner, 1970). This process occurs soon after the initial deposition of sediment and probably ceases to operate above temperatures of $60^{\circ}C$ (Orr, 1974). Hydrogen sulfide also can be generated at high temperatures and pressures by the thermal cleavage of organic sulfur compounds and nonmicrobal sulfate reduction. However, much of the hydrogen sulfide generated at depth is incorporated into immature pertoleum, forming organic sulfur compounds (Kartsev and others, 1959; Ho and others, 1974). Thus, none of the above processes can be relied upon to justify the use of hydrogen sulfide as the reductant responsible for the bleaching of shallow sandstones in the study areas.

Evans, Rogers, and Baily (1971) have shown that hydrogen sulfide can be generated in shallow reservoirs by the alteration that results from the introduction of anerobic bacteria into the reservoirs by descending meteroic waters. The bacteria select their food sources from the petroleum hydrocarbons and derive their oxygen supply by the reduction of sulfate ions present in the invading waters. Ground waters in the study areas are favorable for relatively high sulfate concentrations due to the arid conditions under which Permian units were deposited. Gypsum was occasionally observed in the Velma and Eola areas and was common in the Chickasha area. Krauskopf (1967) has summarized the reaction, using methane as the organic reactant, as:

$$2H^{+} + SO_4^{=} + CH_4 \rightarrow H_2S + CO_2 + 2H_2O$$

Hydrogen sulfide released during the alteration of crude oils will react with iron-rich rocks to form pyrite. Pyrite formation will take place according to the following reaction (Kartsev and others, 1959):

$$H_2S + Fe_2O_3 \rightarrow FeS_2 + FeO + 2H_2O$$

Davis (1967) reports that the bacterial alteration of crude oils can take place at depths up to 2700 m but usually at depths less than 1500 m. None of the thicknesses of Permian strata in the study areas exceeds this lower limit, and depth would not be a limiting factor in the application of the mechanism.

Several other nonbiogenic processes can alter the composition of petroleum by the action of meteoric water at shallow depths. The mechanism of water washing flushes away the light hydrocarbon components of crude oil, leaving a denser oil (Milner and others, 1977). Inorganic oxidation of oils near the surface also leaves a heavier oil.

The alteration of oils at shallow depths (less than 1500 m) by the processes of biodegradation, water washing, and inorganic oxidation results in a crude oil that is denser (lower API gravity) and contains a higher sulfur content than unaltered oils (Orr, 1974). Data pertaining to oil density and sulfur content of crude oils produced in the Velma area support the contention that crude oils in the study areas may have been altered by the processes outlined above. The deepest producing zone in the Velma field is the Bromide zone. Oil produced from this zone has an API gravity of 66.6° and a sulfur content of .43% (Rutledge, 1955). Oil produced from the shallow Hoxbar, Deese, and Springer zones have API gravities of 29.0°, 28.5° and 27.1°, respectively. Sulfur contents of these shallow oils range from 1.02% to 1.34%. The increase in density and sulfur content of the shallow oils is good evidence that they have undergone alteration.

Other mineralogical data also support the alteration hypothesis. The final result of the oxidation of ascending crude oil is a solid petroleum residue or tar (Milner and others, 1977). Such residues were observed throughout the Velma and Eola fields.

Hydrogen sulfide is not stable in an oxidizing environment. As the gas encounters oxygenated ground water, the following reaction takes place:

$$H_2S + 1/2\ O_2 \rightarrow S^{\circ} + H_2O$$

where O_2 is the oxygen in ground water. This reaction was used to explain the deposition of native sulfur by Davis and

Kirkland (1970) and offers a viable explanation for the native sulfur observed in the Velma and Eola areas.

Ho and others (1974) suggest that petroleum alteration is not only likely to take place at shallow depths, but also along unconformities. Donovan (1972) also emphasizes the importance of an unconformity in the alteration of sandstones in the Cement area. Truncated, Pennsylvanian formations containing hydrocarbon reservoirs are present below an angular unconformity in the Velma, Eola, and Chickasha areas. The unconformities in these fields intersect high-angle normal and reverse faults which cut major reservoirs at depth. These faults could act as conduits for the upward movement of petroleum-bearing fluids, channelling hydrocarbons into the overlying Permian strata. The unconformities in these fields are all overlain by pyrite cement zones. It is interesting to note that the Altus field, which shows no evidence of pyrite mineralization, does not overlie truncated Pennsylvanian reservoir formations or faults cutting reservoir formations.

The purpose of the previous discussion has been to show that hydrogen sulfide generated by the alteration of ascending petroleum-bearing fluids is the best reductant for the bleaching of sandstone intervals in the study areas. This alteration not only explains the bleaching, but also the formation of pyrite, sulfur, solid petroleum residues, and the changes in denisty and sulfur content of the Velma crude oils. The structural and stratigraphic features of the areas also have been shown to be well suited for the operation of this mechanism. One important secondary cement has been neglected, however. This is the carbonate cement in the sandstone intervals.

An explanation of the origin of the carbonate cement is complicated by the fact that the cement is associated with both iron oxide and iron sulfide, indicating its deposition is not the result of a simple reduction-oxidation system. A process (or processes) must be established which allows for the association of carbonate cement with iron minerals formed in both reducing and oxidizing environments.

Donovan (1972) found that the isotopic ratios of the oxygen and carbon in the carbonate cement in the Cement area varied systematically in relation to the structure. If the carbonate cement in the bleached sandstone intervals was the result of the same chemical process, the isotopic ratios would be uniform throughout the field. The author's data indicate that more than one mechanism is responsible for the genesis of the carbonate cement. Donovan identified two different types of cement on the basis of the isotopic ratios. Near the crest of the Cement anticline and overlying the trace of a major thrust fault at depth, the carbonate cement was interpreted as being the result of the oxidation of petroleum. Thode and others (1959) have shown that carbonate cement results from the reduction of sulfates in the presence of hydrocarbons. Kartsev and others (1959) summarize this reaction as:

$$C_nH_m + 3CaSO_4 \rightarrow 3CaCO_3 + CO_2 + H_2O + 3H_2S$$

This reaction results in the deposition of a calcite cement and the generation of hydrogen sulfide, which can react with hematite to form pyrite. The reaction does not require the presence of anerobic bacteria to take place (Toland, 1960). The formation of carbonate and pyrite cements thus can be initiated by both organic and inorganic means. This reaction has been used by many other authors to explain the secondary development of carbonate cements (Todd, 1963; Chepikov and others, 1963; Silverman and others, 1960; Spotts and Silverman, 1966; Levandowski and others, 1973).

Donovan (1972) reports that isotopic ratios also indicate that the influence of oxidized petroleum on the deposition of carbonate cements diminishes away from the crest of the structure. The mechanism of micropore filtration was used to explain the formation of carbonate cement in areas where petroleum was not available to react with sulfate. The micropore filtration process operates by the movement of carbonate-rich waters through sandstone into semi-permeable shale or mudstone. The negatively-charged ions in the clays making up the shale and mudstone repulse the carbonate anions in the migrating formation water and concentrate the anions in the sandstones (DeSitter, 1947; Bredehoeft and others, 1963). The anions attract calcium cations, and upon saturation calcite is precipitated as a cement.

During both the hydrocarbon oxidation and micropore filtration processes, magnesium ions present in the salts of the formation waters could substitute for calcium ions, allowing for the deposition of dolomite as well as calcite cement.

The carbonate cement formed by micropore filtration could be associated with iron oxide and pyrite, while that formed by the reaction between sulfate and petroleum could only be associated with iron minerals formed under reducing conditions (i.e., pyrite). These two processes adequately explain the mineralogical associations observed in the study areas.

The area in which Donovan (1972) mapped the isotopic composition of surficial carbonate cement in the eastern part of the Cement field and the area in which the pyrite cement zone was mapped in the Chickasha field overlap in sections 6, 7 and 8, T.5N., R.8W. (Figure 21). The isotopic composition of the surficial cement within the pyrite cement boundary was interpreted by Donovan to be at least partially the result of the oxidation of ascending hydrocarbons. This correlation between petroleum derived carbonate at the surface and pyrite mineralization at depth is further evidence for the formation of pyrite by the reaction of petroleum hydrocarbons and sulfate.

CHAPTER V

THE MIGRATION AND ALTERATION OF PETROLEUM IN THE VELMA, EOLA, CHICKASHA, AND ALTUS OIL FIELDS

Donovan (1972) used variabilities in the physical and chemical properties of crude oils and the isotopic composition of carbonate cements to trace the migratory history of hydrocarbons in the Cement Field. It also is possible to trace the movement of hydrocarbon-bearing fluids in the study areas, not by crude oil composition or isotopic ratios, but by the distribution of pyrite cement within the field. Donovan emphasized the theory of petroleum migration put forth by Baker (1969) as being best able to explain his observations in the Cement field. The chemical and mineralogical manifestations of migrating hydrocarbons in the study areas are also best explained by Baker's theory.

Baker (1969) is a proponent of the in-situ or "mineral-like" origin of oil. This theory proposes that hydrocarbons are precipitated directly within the reservoir formations and that a hydrocarbon accumulation does not move as a body from source beds to reservoir rocks. Instead, the hydrocarbons migrate in solution within moving connate water. The concentration of hydrocarbon compounds in the connate water is extremely small, on the order of 1-5 ppm. The hydrocarbons migrate until a suitable environment is encountered for precipitation. This environment is characterized by a high concentration of dissolved salts. The solubility of hydrocarbons decreases with increasing salinity, and it was pointed out in the previous chapter that in a sequence of sandstones and mudstones, salts were concentrated within the sandstone intervals by the mechanism of micropore filtration (DeSitter, 1947; Bredhoeft, 1963). The author proposes that this "salting-out" mechanism is responsible for the accumulation of hydrocarbons in sandstone reservoirs.

For a petroleum accumulation to form from the precipitation of the miniscule amounts of hydrocarbons dissolved in connate waters, vast amounts of water are required to move through sandstones into semi-permeable shales. The forces responsible for the movement of this volume of connate water are brought about by the hydrodynamics of the entire sedimentary basin. The movement of water within a basin is due to the continuous compaction of sediments. This compaction is accomplished by the expulsion of water from the center of the basin outward and upward. Baker (1969) recognizes three zones of water movement. The compaction zone is found in the center of the basin where the compaction forces are the greatest. The edge of the basin is the artesian zone which channels meteoric water inward. The zone in which the artesian, meteoric water and basinal, connate water combine is the mixing zone. The Velma, Eola, and Chickasha fields lie within the mixing zone of the Anadarko basin. The mixing of connate and meteoric waters is responsible for the alteration of the crude oils in the shallow reservoirs within the fields.

As connate water is expelled from the compaction zone, it dissolves hydrocarbons present in the zone and migrates toward the edge of the basin. An accumulation is formed where sandstones are encountered whose formation waters contain a sufficient concentration of dissolved salts. Anticlines would be likely centers for the concentration of waters moving outward from the central basin.

This theory helps explain the restriction of rock bleaching and pyrite mineralization to sandstones. The mixing of waters containing hydrocarbons and sulfate went on outside the sandstone intervals as well as in them. Yet, no bleaching of mudstones was observed in any of the study areas. The explanation that hydrocarbons were not sufficiently concentrated to allow for a reaction with sulfate outside of the sandstone is plausible using Baker's theory.

The reaction between hydrocarbons and sulfate would continue until hydrocarbons ceased to accumulate within the sandstone, all of the sulfate was consumed, or the sandstone was rendered completely impermeable by cementation. A porus sandstone with no porducable hydrocarbons would be the result of the first instance. A reservoir containing producable hydrocarbons would be the effect of the second case, and an impermeable sandstone would result from the third situation. Levandowski and others (1973) have explained the formation of permeability barriers within the Denver basin by the complete cementation of sandstone by the sulfate-hydrocarbon reaction. These permeability barriers prevented the migration of petroleum up-dip during subsequent structural tilting.

A petroleum accumulation would form within a reservoir sandstone with an oil-water contact if hydrocarbons accumulated at a faster rate than they could be oxidized by sulfate. The subsequent reaction with sulfate would take place at the oil-water contact, with carbonate cements being formed outside the oil saturated zone. This could lead to the development of a "frozen in" or diagenetic trap as defined by Wilson (1977).

It was shown in the previous chapter that pyrite could only be formed in the presence of hydrocarbons. This relationship between pyrite mineralization and areas of petroleum accumulation can be used to trace the migratory history of petroleum-bearing fluids in the Velma, Eola, and Chickasha fields.

The primary migration of hydrocarbon-bearing fluids in the three fields could have occurred before and/or after the Arbuckle and Wichita orogenies. Harlton (1964) reports that that petroleum was already trapped prior to the final structural deformation of the Eola area. In the case of entrapment preceding structural deformation, petroleum accumulation would have been the result of secondary migration within the same reservoir. If primary migration occurs after structural deformation, petroleum accumulation will be the result of the preferential movement of fluids towards structural highs (Baker, 1969). Because the expression of fluids away from the central basin is a continuous process, it is likely that migration and accumulation occurred before, during, and after the structural deformation of the study areas.

The migration of fluids into Permian strata from underlying Pennsylvanian formations was through high-angle faults that cut the deep reservoirs. These faults acted as avenues of superior vertical permeability for leaking fluids. The intersection of these faults with unconformities developed at the crests of the Pennsylvanian structures allowed for the lateral migration of fluids at the base of the Permian section.

The ascending fluids passed through sandstones which contained high salt concentrations due to micropore filtration. Sulfate ions and possibly anerobic bacteria were also in the sandstones due to a possible influx of descending meteoric water. The hydrocarbons precipitated from solution in the saline waters and reacted with sulfate to generate carbonate cement and hydrogen sulfide. The hydrogen sulfide reacted with iron oxide to form pyrite. Near the surface, hydrogen sulfide reacted with the oxygen in ground water to form native sulfur.

The boundaries of the pyrite cement zones formed in the fields are basically sharp and vertical, indicating that petroleum bearing fluids moved in a predominately vertical direction, implying that the hydrocarbon content of the expressed fluids and/or the volume and local direction of fluid movement was not constant. This situation is not unusual when the discontinuous nature and paucity of permeable sandstones within the Permian sections is considered.

The faults which intersect the unconformity in the Velma field are those that bound the central horst at the crest of the Pennsylvanian anticline (Figure 4). These faults cut the Springer zone, the most prolific producing horizon in the field. The zone also is truncated at the Permian-Pennsylvanian unconformity. The pyrite cement zone directly overlies the area of maximum fault development. This situation emphasizes the importance of faults in the development of vertical permeability.

The pyrite cement zone in the Eola field generally overlies the Washita Valley fault. This fault intersects the Bromide producing zone at depth (Figure 12). Fluids moving along this fault were not directly expressed into Permian strata, but migrated through several hundred meters of limestone conglomerate. The lack of pyrite mineralization within the conglomerate is due to the absence of iron minerals in the limestone sequence. The mineralized zone also is situated slightly south of the main producing zone (Figure 16). This offset could be caused by the migration of fluids up structural as well as depositional dip within the fan-like wedge of conglomerate. If this is the case, migration of fluids along other faults could also have contributed to the development of pyrite cements.

Vertical migration of fluids in the Chickasha field was centered along the major thrust fault which intersects the Permian-Pennsylvanian unconformity (Figure 18). The importance of hydrocarbon leakage along an extension of this fault in the Cement area was stressed by Donovan (1972). The introduction of migrating fluids into Permian strata resulted in the accumulation of significant amounts of oil and gas in shallow Permian sandstones.

The lack of mineralization indicative of hydrocarbon migration in the Altus field probably is due to the few porus and permeable sandstones in the section. The chlorite matrix of the sandstones would prevent the concentration of dissolved salts in specific intervals and the subsequent formation of hydrogen sulfide and pyrite. The statement by Ryniker and others (1959) that it is necessary to enhance permeability within reservoirs by hydraulic fracturing before significant quantities of petroleum can be produced supports this hypothesis. If this is the case, the accumulation of petroleum in the field would be the result of secondary migration rather than primary deposition of hydrocarbons within the reservoir formations.

The previous discussion has been an attempt to show not only how the diagenesis of reservoir rocks can be used to trace the migratory history of associated crude oils, but also to elucidate possible mechanisms for the primary migration of hydrocarbons from source areas. The similar diagenetic histories of the Velma, Eola, and Chickasha fields plus the recognition of similar alteration in the Cement field by Donovan (1972) and the Carter-Knox and Red River areas by Olmsted (1975), imply that these diagenetic changes are not isolated and could occur in areas with analogous stratigraphic, structural, and hydrodynamic characteristics. These characteristics include the development of faulted anticlines; proximity of red beds to the structure; a source of sulfate rich water; and continuous migration of hydrocarbon-bearing fluids.

CHAPTER VI

PRINCIPAL OBSERVATIONS AND CONCLUSIONS

The principal observations of this study are:

1. Permian sandstones which are typically red are altered to various shades of white over the crests of the Velma, Eola, and Chickasha anticlines.

    a. This color change is due to a change in cementing materials from an association of clay, limonite, and hematite away from the anticlines to ferroan calcite, ferroan dolomite, and, in in some places, pyrite over the anticlines.

    b. All of the Permian sandstones in the three fields are bleached in this manner.

    c. Bleaching is restricted to sandstone intervals; claystones, shales, and siltstones are red.

2. Pyrite cement is developed in a zone within the three fields.

    a. The average pyrite content of sandstones within the zones ranges from 2-4% and varies randomly in amount horizontally and vertically.

    b. The pyrite cement zone boundary is basically sharp and vertical.

c. The pyrite cement zone overlies pre-Permian faults and productive areas at depth and is elongated along the structural trend.

3. Native sulfur was present in the Velma and Eola fields at depths ranging from 12 to 580 m.

4. Solid petroleum residues are common throughout the Velma and Eola fields.

5. Clayey, arkosic sandstones within the Altus anticline show no evidence of having undergone color changes.

The principal conclusions drawn from these observations are:

1. The bleaching of Permian sandstones was the result of the reduction of iron oxides in the presence of petroleum.

a. The most likely reducing agent was hydrogen sulfide associated with petroleum and/or generated by a reaction between hydrocarbons and sulfate ions.

b. The hydrogen sulfide reacted with iron oxide to form pyrite and with oxygen in ground water to form sulfur.

2. The sulfate ions and possibly anaerobic bacteria were introduced into the altered sandstones by descending meteoric waters.

3. Secondary carbonate cement was a product of the oxidation of hydrocarbons by sulfate and micropore filtration.

4. Hydrocarbons were introduced into Permian strata by ascending fluids from Pennsylvanian reservoirs.

    a. Vertical migration of hydrocarbon-bearing fluids was facilitated by high-angle normal and reverse faults which cut reservoir formations at depth.

    b. Lateral migration was enhanced by unconformities present at the base of the Permian sections.

5. Pyrite mineralization delineates areas of hydrocarbon accumulation.

6. Alteration and mineralization of sandstones in the Altus field did not take place because of an abundance of chlorite in the rock matrix.

REFERENCES CITED

Aurin, F. L., H. G. Officer, and C. N. Gould, 1926, The Subdivision of the Enid Formation: Am. Assoc. Petroleum Geologists Bull., v. 10, pp. 786-799.

Baas Becking, L. G. M., I. R. Kaplan, and D. Moore, 1960, Limits of the Natural Environment in Terms of pH and Oxidation-Reduction Potentials: Jour. Geology, v. 68, pp. 243-284.

Baker, E. G., 1969, A Geochemical Evaluation of Petroleum Migration and Accumulation, in Nagy, Bartholomew, and Umberto, eds., Fundamental Aspects of Petroleum Geochemistry: New York, Elsevier, pp. 299-329.

Berner, R. A., Sedimentary Pyrite Formation: Am. Jour. Sci., v. 268, pp. 1-23.

Birdseye, H. S., 1957, The Relation of the Ambrosia Lake Uranium Deposits to a Preexisting Oil Pool, in Geology of Southwestern San Juan Basin, 2nd Field Conf.: Four Corners Geol. Soc., pp. 26-29.

Bredehoeft, J. D., C. R. Blyth, W. A. White, and G. B. Maxey, 1963, Possible Mechanism for Concentration of Brines in Subsurface Formations: Am. Assoc. Petroleum Geologists Bull., v. 47, pp. 257-269.

Brown, O. E., 1937, Unconformity at the Base of the Whitehorse Formation, Oklahoma: Am. Assoc. Petroleum Geologists Bull., v. 21, pp. 1534-1556.

Bunn, J. R., 1930, Jefferson County, in Oil and Gas In Oklahoma: Okla. Geol. Survey Bull. 40, v. 2, pp. 341-381.

Chase, G. W., 1954, Permian Conglomerate around Wichita Mountains, Oklahoma: Am. Assoc. Petroleum Geologists Bull., v. 38, p. 2028-2035.

Chepikov, K. P., Y. P. Yermoiova, and N. A. Orlov, 1963, Corrosion of Quartz Grains and Examples of the Possible Effect of Oil on the Reservoir Properties of Sandy Rocks: Akad. Nauk SSSR Proc., Earth Sci. Sec., v. 140, pp. 227-245.

Collins, A. G., 1969 Chemistry of Some Anadarko Basin Brines Containing High Concentrations of Iodide, Chem. Geol., v. 4, pp. 169-187.

_______________ 1975, Geochemistry of Oilfield Waters-developments in Petroleum Science 1, New York. Elsevier, p. 496.

Davis, L. V., 1955, Geology and Ground Water Resources of Grady and Stephens Counties, Oklahoma: Okla. Geol. Survey Bull., n. 73, p. 184.

Davis, J. B., 1967, Petroleum Microbiology, New York, Elsevier, p. 604.

____________, D. W. Kirkland, 1970, Native Sulfur Deposition in Castille Formation, Culberson County, Texas: Economic Geol., v. 65, pp. 107-121.

DeSitter, L. U., 1947, Diagenesis of Oil-Field Brines: Am. Assoc. Petroleum Geologists, v. 31, pp. 2030-2040.

Donovan, T. J., 1972, Surface Mineralogical and Chemical Evidence for Buried Hydrocarbons, Cement Field Oklahoma: Ph.D. thesis, Univ. Calif., Los Angeles, p. 117.

_______________ 1974, Petroleum Microseepage at Cement, Oklahoma-Evidence and Mechanism: Am. Assoc. Petroleum Geologists Bull., v. 58, pp. 429-446.

Dott, R. H., 1930, Garvin County, in Oil and Gas in Oklahoma: Okla. Geol. Survey Bull. 40, v. 2, pp. 119-143.

Evamy, B. D., 1963, The Application of a Chemical Staining Technique to a Study of Dedolotimization: Sedimentology, v. 2, pp. 164-170.

Evans, N., 1931, Stratigraphy of Permian Beds of Northwestern Oklahoma: Am. Assoc. Petroleum Geologists Bull., v. 15, pp. 405-439.

Evans, C. R., M. A. Rogers, and N. J. L. Bailey, 1971, Evolution and Alteration of Petroleum in Western Canada: Chem. Geol., v. 8, pp. 147-170.

Fay, R. O., 1964, The Blaine and Related Formations of Northwestern Oklahoma and Southern Kansas: Okla. Geol. Survey Bull., n. 98.

___________ 1968, Geology of Region II, in Appraisal of the Water and Related Land Resources of Oklahoma: Okla. Water Resources Board Pub. 24, pp. 21-24.

__________,1969, Geology of Region IV, in Appraisal of the Water and Related Land Resources of Oklahoma: Okla. Water Resources Board Pub. pp. 21-24.

Flood, J. R., 1969, Areal Geology of Western Jefferson County, Oklahoma: Unpub. M. S. thesis, Univ. of Oklahoma, p. 61.

Folk, R. L., 1974, Petrology of Sedimentary Rocks: Hemphill Publishing Co.: Austin, Texas.

Garrels, R. M., and C. L. Christ, 1965, Minerals, Solutions, and Equilibria: Harper and Row, New York.

Goddard, E. N., P. D. Trask, and others, 1963, Rock Color Chart: Geol. Soc. America.

Gouin, E., 1926, The Geology of the Oil and Gas Fields of Stephens County, Oklahoma: Okla. Geol. Survey Bull., n. 40-E, pp. 2-67.

__________, 1930, Stephens County, in Oil and Gas in Oklahoma: Okla. Geol. Survey, v. 2, pp. 2-66.

__________, 1956, Surface Criteria of Southern Oklahoma Oil Fields, in Petroleum Geology of Southern Oklahoma: Am. Assoc. Petroleum Geologists, v. 1, pp. 14-35.

Gould, C. N., 1924, A New Classification of the Permian Red Beds of Southwestern Oklahoma: Am. Assoc. Petroleum Geologists Bull., v. 8, pp. 322-341.

Green, D. A., 1936, Permian and Pennsylvanian Sediments Exposed in Central and West Central Oklahoma: Am. Assoc. Petroleum Geologists Bull., v. 20, pp. 1454-1475.

Ham, W. E., 1960, Middle Permian Evaporites in Southwestern Oklahoma, in Report of the Twenty First Session, Norden, Part 12: Int. Geol. Cong., Copenhagen, pp. 138-151.

__________, C. A. Merritt, and E. A. Frederickson, 1957, Field Conference on Geology of the Wichita Mountain Region, May 2-4, 1957: Okla. Geol. Survey Guidebook V, p. 58.

__________, J. L. Wilson, 1967, Paleozoic Epeirogeny and Orogeny in the Central U. S.: Am. Jour. Sci., v. 265, pp. 332-407.

Harlton, B. H., 1960, Stratigraphy of Cement Pool and Adjacent Areas, Caddo and Grady Counties, Oklahoma: Am. Assoc. of Petroleum Geologists Bull., v. 44, pp. 200-226.

____________________, 1964, Tectonic Framework of Eola and Southwest Hoover Oil Fields and West Timbered Hills Area, Garvin and Murray Counties, Oklahoma, Am. Assoc. Petroleum Geologists, v. 48, pp. 1555-1565.

Hart, D. L., Jr., 1974, Reconnaissance of the Water Resources of the Ardmore and Sherman Quadrangles, Southern Oklahoma: Okla. Geol. Survey Hydrologic Atlas.

Hem, J. D., and W. H. Cropper, 1959, Survey of Ferrous-Ferric Chemical Equibibria and Redox Potentials: U. S. Geological Survey Water-Supply Paper 1459-A, p. 31.

Herrmann, L. A., 1961, Structural Geology of Cement-Chickasha area, Caddo and Grady Counties, Oklahoma: Am. Assoc. Petroleum Geologists Bull., v. 45, pp. 1971-1993.

Ho, T. Y., M. A. Rogers, H. V. Drushell, and C. B. Koons, 1974, Evolution of Sulphur Compounds in Crude Oil: Am. Assoc. Petroleum Geologists Bull., v. 58, pp. 2338-2348.

Hoffman, P., J. F. Dewey, and K. Burke, 1974, Aulacogens and Their Genetic Relaton to Geosynclines, with a Proterzoic Example from Great Slave Lake, Canada, in Dott, R. J., Jr., and R. H. Shaver, eds., Modern and Ancient Geosynclinal Sedimentation (Kay volume): Soc. Paleontologists and Mineralogists Spec. Pub. 19, pp. 38-55.

Kartsev, A. A., S. A. Tobasaranskii, M. I. Subbota, and G. A. Moglievskii, 1959, Geochemical Methods of Prospecting and Exploration for Petroleum and Natural Gas: Univ. of Calif. press, Berkely.

Kerr, P. F., 1958, Uranium Emplacement in the Colorado Plateau: Geol. Soc. America Bull., v. 69, pp. 1075-1111.

Krauskopf, K. B., 1967, Introduction to Geochemistry: New York, McGraw-Hill, Inc., p. 719.

Levansowski, D. W., M. E. Kaley, S. R. Silverman, and R. G. Smalley, 1973, Cementation in Lyons Sandstone and its Role in Oil Accumulation, Denver Basin, Colorado: Am. Assoc. Petroleum Geologists Bull., v. 57, p. 2217-2245.

MacLachlan, M. E., 1967, Paleotectonic Investigations of the Permian System in the United States: U. S. Geol. Survey Prof. Paper 515-E, pp. 85-92.

Milner, C. W., M. A. Rogers, and C. R. Evans, 1977, Petroleum Transformations in Reservoirs, Jour. Geochemical Expl.: v. 7, pp. 101-153.

Miser, H. D., 1954, Geologic Map of Oklahoma: U. S. Geol. Survey and Okla. Geol. Survey.

Moulton, G. F., 1926, Some Features of Red Bed Bleaching: Am. Assoc. Petroleum Geologists Bull., v. 10, pp. 302-311.

Munn, M. J., 1914, Reconnaisance of the Grandfield District, Oklahoma: U. S. Geol. Survey Bull., v. 547, p. 85.

O'Brien, B. E., 1963, Geology of East-Central Caddo County Oklahoma: Unpub. M. S. thesis, Univ. Okla., p. 72.

Olmsted, R. W., 1975, Geochemical Studies of Uranium in South-Central Oklahoma: Unpub. M. S. thesis, Okla. State Univ., p. 116.

Orr, W. L., 1974, Changes of Sulfur Content and Isotopic Ratios of Sulfur During Petroleum Maturation-Study of Big Horn Basin Oils: Am. Assoc. Petroleum Geologists, v. 58, p. 2295-2318.

Powell, B. N., D. W. Phelps, 1977, Igneous Cumulates of Wichita Province and Their Tectonic Implications: Geology, v. 5, pp. 52-56.

Pruatt, M. A., 1975, The Southern Oklahoma Aulacogen: A Geophysical and Geological Investigation: Unpup. M. S. thesis, Univ. Okla., p. 59.

Reeves, F., 1921, Geology of the Cement Oil Field, Caddo County, Oklahoma: U. S. Geol. Survey Bull., n. 72b, pp. 41-85.

Rutledge, R. B., 1954, The Velma Oil Field, Stephens County, Okla.: Tulsa Geological Soc. Digest, v. 22, pp. 40-52.

_______________, 1955, The Velma Oil Field, Stephens, County: Proceedings 4th Subsurface Geological Sym., pp. 49-66.

Ryniker, C., C. G. Shortridge, and R. W. Maxwell, 1959, Altus Field, Jackson County, Oklahoma: Petroleum Geology of Southern Oklahoma, v. 2: Am. Assoc. Petroleum Geologists, pp. 1165-1179.

Self, R. P., 1966, Petrology of the Duncan Sandstone (Permian) of South-Central Oklahoma: Unpub. M. S. thesis, Univ. Okla., p. 133.

Silverman, S. R., D. W. Levandowski, and L. C. Bonham, 1960, Carbonate from Oil: Paper presented at Soc. Econ. Paleontologists and Mineralogists Nat'l. Mtg. Altantic City, New Jersey, (unpub.: not heard).

Spotts, J. H. and S. R. Silverman, 1966, Organic Dolomite from Point Fermin, Calif.: Am. Mineralogist, v. 51, pp. 1114-1155.

Swesnik, R. M. and T. H. Green, 1950, Geology of Eola Area, Garvin County, Oklahoma: Am. Assoc. Petroleum Geologists, v. 34, pp. 2176-2199.

Thode, H. G., R. K. Wanless, and R. Walloch, 1954, The Origin of Native Sulphur Deposits from Isotope Fractionation Studies: Geochimica et Cosmochemica, v. 5, pp. 286-298.

Todd, T. W., 1963, Post-depositional History of Tensleep Sandstone (Pennsylvanian), Big Horn Basin, Wyoming: Am. Assoc. Petroleum Geologists Bull., v. 47, pp. 599-616.

Toland, W. G., 1960, Oxidation of Organic Compounds with Aqueous Sulfate: Jour. Amer. Chemical Society, v. 82, pp. 1911-1916.

Tomlinson, C. W., 1930, Carter County, in Oil and Gas in Oklahoma, v. 2, p. 239-310.

________________, and M. McBee, Jr., 1959, Pennsylvanian Sediments and Orogenies of Ardmore District, Oklahoma, in Petroleum Geology of Southern Oklahoma, v. 2: Am. Assoc. Petroleum Geologists, pp. 3-52.

Waterschoot van der Gracht, W. A., J. M. Van, 1931, Permo-Carboniferous Orogeny in South-Central U. S.: Am. Assoc. Petroleum Geologists Bull., v. 15, pp. 991-1057.

Wickham, J., M. Pruatt, R. Leon, T. Thompson, 1975, The Southern Oklahoma Aulacogen: Absts. with Programs: An. Mtg. Geol. Soc. America, v. 7, p. 1332.

Wilson, H. H., 1977, "Frozen-in" Hydrocarbon Accumulations of Diagenetic Traps-Exploration Targets: Am. Assoc. Petroleum Geologists, v. 61, pp. 483-491.

APPENDIX

WELL LOCATIONS AND SAMPLE INTERVALS

Velma Field

Operator, Well Number	Location	Sample Interval (ft)
Skelly Oil Co. #1 Cleveland	1-1S-5W, NE NE SW	300 - 3000
Mid-Continent #1 Parks	3-1S-5W, SE SW SE	300 - 3100
Murry Oil Co. #1 Wilkerson	8-1S-5W	500 - 1020
Amoranda Hess Corp. #1 Riviere	9-1S-5W, NE NE SE	500 - 1580
McCasland Oil Co. #1 Riviere	9-1S-5W, SE NE NE	500 - 1460
Turner Oil Co. #3A Riviere	10-1S-5W, NE NW SE	80 - 1040
Gulf Oil Corp. #1 Doma	11-1S-5W	240 - 1950
Carter Oil Co. #1 Jones	13-1S-5W, SW SW SE	580 - 2650
Gulf Oil Corp. #2 Spears	14-1S-5W, SW NW SW	100 - 1420
Skelly Oil Co. #8 Humphries	14-1S-5W, NE SE NE	580 - 2810
Amanda Hess Corp. #1 Britton	15-1S-5W, SW SW SW	300 - 1260
Winkler Oil Co. #1 Parker	16-1S-5W, SE SW NE	260 - 1100
Champlin Oil Co. #1 Wilkerson	17-1S-5W, SE NE NE	400 - 1540
Continental Oil Co. #3 Duncan Bank	21-1S-5W, NE NW NE	400 - 1400
Skelly Oil Co. #1 Spears	22-1S-5W, NW SW NW	0 - 880
Lone Star Oil Co. #5 Emeison	22-1S-5W, SW NW SE	200 - 1240
Skelly Oil Co. #4 Mudge	23-1S-5W, NW SW NW	0 - 1300
Skelly Oil Co. #1 Davis	24-1S-5W, NW SE SE	280 - 2270

Operator, Well Number	Location	Sample Interval (ft)
Skelly Oil Co. J-24 Fensley	24-1S-5W, SW NE SW	0 - 2020
Skelly Oil Co. #1 Crosby	25-1S-5W, SW SW NW	100 - 1320
Skelly Oil Co. #2 Fensley - H	25-1S-5W, NE NW NE	0 - 1960
Skelly Oil Co. #34 Bless	26-1S-5W, C NW SW	100 - 1100
Skelly Oil Co. #1 Templer	26-1S-5W, C NW SE	100 - 900
Skelly Oil Co. #84 Selby	26-1S-5W, SE EN SW	0 - 840
Skelly Oil Co. #8 W. B. Green	27-1S-5W, NW SW SE	0 - 1960
Mudge Oil Co. #4 Swanson	28-1S-5W, NW SW NE	500 - 1420
Skelly Oil Co. #27 Franklin	34-1S-5W, SE SW SE	400 - 1220
Skelly Oil Co. #28 Stifel	35-1S-5W, C NW	0 - 920
Skelly Oil Co. #1-D Martin	36-1S-5W, C SE NW	0 - 1780
Smith Oil Co. #1 Darity	17-1S-4W, SW SE SW	1000 - 2920
Skelly Oil Co. #8-E Martin	30-1S-4W, NE SW SW	540 - 2240
Beard Pet. #1 Gates	31-1S-4W, SW SE NW	400 - 1910
Amanda Hess Corp. #2 Cox	33-1S-4W, NE NW SW	280 - 2300
Elliot and Van Fossen #1 Magnolia	5-2S-4W, SE SE SE	600 - 800
Skelly Oil Co. #1 Leonard	6-2S-4W, SW SW NE	40 - 1600
Magnolia #12 Quackenbush	8-2S-4W, C NW SW	40 - 960
Skelly Oil Co. #1 Killingsworth	1-3S-5W, NW SW SE	200 - 1160
Pure Oil Co. #25 Hassell	2-2S-5W, NE NE NW	0 - 1060
Weller Oil Co. #1 Dunlap	11-2S-5W, SW NW NE	500 - 900
Skelly Oil Co. #2 Henry	12-2S-5W, NE NE SE	200 - 1160

Eola Field

Operator, Well Number	Location	Sample Interval (ft)
Cox Oil Co. #2 Tussy	3-1N-3W, SE NE SE	1000 - 1940
Shell Oil Co. #1 Johnson	5-1N-3W, C SE NW	1400 - 2360
Shell Oil Co. #1 Cole Cook	5-1N-3W, C SW SE	140 - 1220
Shell Oil Co. #1 Cook	5-1N-3W, SE SE	1000 - 1960
Skaggs Oil Co. #3 Good	9-1N-3W, NE NE SE	1000 - 2120
Beard Pet. #1 Harmeyer	6-1N-eW, SE NE NE	1500 - 2460
Republic Oil Co. #1 Blanton	6-1N-3W, SW NE SW	1600 - 2880
Shell Oil Co. #2 Rose	6-1N-3W, SW NW SE	0 - 1520
Shell Oil Co. #1 Snodgrass	7-1N-3W	300 - 1220
Vickers Pet. #1 Cole	8-1N-3W	1900 - 3020
Sohio Oil Co. #1 Wood	10-1N-3W, N½ SW NE	100 - 2420
Magnolia Oil Co. #31 S.H. Cowan	10-1N-3W, SW SE SW	1800 - 1920
Stranolind Oil Co. #1 Wittens	11-1N-3W, SE NE NE	2700 - 2840
Payne Oil Co. #1 Hefner	12-1N-3W, NE NE SW	300 - 3780
Westheimer Oil Co. #1 Pierce	13-1N-3W, NW NE SW	100 - 1220
Wolf Oil Co. #1 Rader	13-1N-3W, S½ SW NW	1000 - 2120
Home Pet. #1 Cowan	14-1N-3W, NE SW SE	400 - 1640
Home Pet. #2 Newberry	14-1N-3W, NW SE SW	500 - 1800
Magnolia Oil Co. #30 Cowan	15-1N-3W, SE NE SW	100 - 1220
Magnolia Oil Co. #3 Cowan	15-1N-3W, SE NE SW	100 - 1220
Alspaugh Oil Co. #1 Ringer	15-1N-3W, NE NE NE	400 - 1620
W. Hart Oil Co. #1 Pernell	16-1N-3W, NE NE NE	900 - 2020

Operator, Well Number	Location	Sample Interval (ft)
Fell Oil Co. #9 Derdyn	17-1N-3W, E½ SE NW	40 - 1800
Patsy Oil Co. #2 Derdyn	17-1N-3W, SW SE SE	100 - 1220
Texas Pacific Railroad #2 Derdyn	18-1N-3W, C NE NE	300 - 1420
Skelly Oil Co. #1 John	19-1N-3W, SW SW SE	800 - 1840
Atchey-Merrick Oil Co #1 Derdyn	20-1N-3W	1200 - 2320
Phillips Pet. #1 Minerva	21-1N-3W, NE SW NE	200 - 1320
Magnolia Oil Co. #4 Gabriel	23-1N-3W, W½ NW SW	0 - 2120
Carr Oil Co. #1 Hart	25-1N-3W, NW SW SW	500 - 1300
Vickers Oil Co. #1 Ferguson	6-1N-2W, SE SW SW	20 - 1960
Republic Oil Co. #1 Harmon	8-1N-2W, SE SW SE	800 - 3000
Stanolind Pet. #1 Horn	8-1N-2W, NE SE NE	840 - 2400
Sohio Oil Co. #1 Dunlap	17-1N-2W, SE SW NE	900 - 1860
Sohio Oil Co. #1 Cassel	18-1N-2W, SE NE NE	100 - 1460
Sunray Oil Co. #3 Romine	19-1N-2W, NW NW SE	100 - 1480

Chickasha Field

Operator, Well Number	Location	Sample Interval (ft)
Sunray Oil Co. #1 Wood	1-4N-8W, SE SE SW	760 - 3800
McCaughey Oil Co. #1 Havins	2-4N-8W, SW NE NE	1500 - 3300
Sinclair Oil Co. #1 Adair	10-4N-8W, C NW NE	1040 - 3960
Alma Oil Co. #6 Pettit	11-4N,8W, SW SW SE	2000 - 3900
Oxley Pet. #1 Kishketon	5-5N-8W, NE NE SW	1900 - 3300
Ohio Oil Co. #1 Loflin	7-5N-8W, C SW SW	2150 - 4500
Phillips Pet. #1 Thomas	7-5N-8W, SW SW NW	1000 - 2100
Skelly Oil Co. #1B Williams	8-5N-8W, SE SE NE	1000 - 3280
Skelly Oil Co. #1 Goodwin	8-5N-8W, SE NW	1500 - 3700
Johnson and Gill Oil Co. #1 Consolidated	14-5N-8W, SW SW SW	240 - 1700
Little Nick Oil Co #1 Oden	15-5N-8W, C NW NE	2300 - 3400
ONG #1 Rider	16-5N-8W, NE NE SE	760 - 4540
ONG #2 Rider	16-5N-8W, NE NW SE	2400 - 3500
Ohio Oil Co. #1 Hemphill	18-5N-8W, NE NW SW	500 - 4220
Sun Oil Co. #1 Garret	21-5N-8W, C SE NW	300 - 3100
Sinclair-Prarie Oil Co. #4A Pooler	22-5N-8W, SE SE NE	620 - 3650
Sinclair-Prarie Oil Co. #6 Charleston	22-5N-8W, C SW SE	680 - 3800
Cooper Oil Co. #1-B Sandford	23-5N-8W, C NW SW	1000 - 3320
Texas Oil Co. #1 Barnett	23-5N-8W, SW NW SE	1200 - 2320
Carter Oil Co. #1 Smith	26-5N-8W, C SE SW	40 - 2900
Magnolia Oil Co. #8 Farwell	26-5N-8W, C SW SE	1000 - 3240

Operator, Well Number	Location	Sample Interval (ft)
ONG #1 Chandler	27-5N-8W, C SE SE	700 - 3420
Apco Oil Co. #1 Thomas	27-5N-8W, NE NE SW	1500 - 3480
Phillips Pet. #1 Duke	28-5N-8W, SW SW SE	1500 - 3100
Phillips Pet. #1 Mona	34-5N-8W, NE NE SE	1560 - 3240
Magnolia Oil Co. #13 H. Smith	35-5N-8W, NE NW NE	1000 - 3320
ONG - #L Duke	35-5N-8W, C NW SW	780 - 3500
Skelly Oil Co. #1 State E	36-5N-8W, SW SE SW	1000 - 2880
Alma Oil Co. #2 Rogers	36-5N-8W, C NW SE	1200 - 2320

Altus Field

Operator, Well Number	Location	Sample Interval (ft)
Fox Oil Co. #2 Mary	2-1N-20W, NW SW	340 - 1640
Gulf Oil Co. #1 McDaniel	3-1N-20W, SW SE NE	1290 - 1540
Badger #1 Elliott	5-1N-20W, NE NE NE	500 - 2020
Gulf Oil Co. #1 Herbart	9-1N-20W, SE SE NE	1100 - 1490
Gypsy Oil Co. #1 Kelly	10-1N-20W	240 - 1000
Gypsy Oil Co. #1 Johnson	11-1N-20W, NW SW SE	1100 - 1640
Vaughn Oil Co. #1-A Garret	12-1N-20W, SW SW SW	40 - 1600
Selby Oil Co. #1 Cobb	22-1N-20W, NE NW NE	1200 - 2000

				VIOLA SIMPSON		
17-01N-02W	SOHIO 1 PEASE-C	08301-10294	*	SIMPSON	103D	1
17-01N-02W	SOHIO 1 VAUGHN	11757-12096	*	SIMPSON	992	5
18-01N-02W	PAN AM 1 BALL UNIT	06558-06564		VIOLA	521	2
18-01N-02W	PAN AM 1 JONES-E	07025-08801		BROMIDE	684	24
18-01N-02W	PAN AM 1 STORY UNIT	06500-08200		BROMIDE	736	47
18-01N-02W	PAN AM 1 WILLIAMS*E	02207-02244		PONTOTOC ✓	671	6
18-01N-02W	PAN AM 1 WILLIAMS-E	02246-02279		PONTOTOC ✓	370	7
18-01N-02W	PAN AMERICAN 1 PICKET UNIT	06929-07299		SIMPSON	323	30
18-01N-02W	SOHIO B-1 CASSELL	06041-11205	*	PONTOTOC SIMPSON	1007	1
18-01N-02W	SOHIO 1 HENDERSON	10141-10410	*	SIMPSON	988	8
18-01N-02W	SOHIO 1 SARAH HODGES	09578-09932	*	SIMPSON	103E	10
18-01N-02W	SOHIO 1 TAYLOR	03005-09580	*	SIMPSON	103M	16
18-01N-02W	SOHIO 1 WHITEHEAD	05608-11771	*	PONTOTOC SIMPSON	978	42
18-01N-02W	SOHIO 1 WHITEHEAD	10335-10844		SIMPSON	447	70
18-01N-02W	SOHIO 2 HODGES	11018-11319	*	SIMPSON	1006	2
19-01N-02W	SOHIO 1 ROMINE	01383-01965		PONTOTOC POSS ARBU	457	4
20-01N-02W	PAN AM C-1 WILLIAMS UNIT	08703-08718		SIMPSON	434	5
20-01N-02W	PAN AM 1 FIELDS	02161-02868		PONTOTOC ✓	431	19
20-01N-02W	PAN AM 1 WILLIAMS C	07382-07990		MCLISH BROMIDE	368	29
20-01N-02W	PAN AM 1 WILLIAMS D	09516-09526		ARBUCKLE	369	3
20-01N-02W	SOHIO 1 MOORE	04430-05186	*	ARBUCKLE BASEMENT	993	1

NOTE: THE ASTERISK (*) AFTER THE DEPTH RANGE INDICATES CORE CHIPS.

				VIOLA SIMPSON		
17-01N-02W	SOHIO 1 PEASE-C	08301-10294	*	SIMPSON	103D	1
17-01N-02W	SOHIO 1 VAUGHN	11757-12096	*	SIMPSON	992	5
18-01N-02W	PAN AM 1 BALL UNIT	06558-06564		VIOLA	521	2
18-01N-02W	PAN AM 1 JONES-E	07025-08801		BROMIDE	684	24
18-01N-02W	PAN AM 1 STORY UNIT	06500-08200		BROMIDE	736	47
18-01N-02W	PAN AM 1 WILLIAMS*E	02207-02244		PONTOTOC ✓	671	6
18-01N-02W	PAN AM 1 WILLIAMS-E	02246-02279		PONTOTOC ✓	370	7
18-01N-02W	PAN AMERICAN 1 PICKET UNIT	06929-07299		SIMPSON	323	30
18-01N-02W	SOHIO B-1 CASSELL	06041-11205	*	PONTOTOC SIMPSON	1007	1
18-01N-02W	SOHIO 1 HENDERSON	10141-10410	*	SIMPSON	988	8
18-01N-02W	SOHIO 1 SARAH HODGES	09578-09932	*	SIMPSON	103E	10
18-01N-02W	SOHIO 1 TAYLOR	03005-09580	*	SIMPSON	103M	16
18-01N-02W	SOHIO 1 WHITEHEAD	05608-11771	*	PONTOTOC SIMPSON	978	42
18-01N-02W	SOHIO 1 WHITEHEAD	10335-10844		SIMPSON	447	70
18-01N-02W	SOHIO 2 HODGES	11018-11319	*	SIMPSON	1006	2
19-01N-02W	SOHIO 1 ROMINE	01383-01965		PONTOTOC POSS ARBU	457	4
20-01N-02W	PAN AM C-1 WILLIAMS UNIT	08703-08718		SIMPSON	434	5
20-01N-02W	PAN AM 1 FIELDS	02161-02868		PONTOTOC ✓	431	19
20-01N-02W	PAN AM 1 WILLIAMS C	07382-07990		MCLISH BROMIDE	368	29
20-01N-02W	PAN AM 1 WILLIAMS D	09516-09526		ARBUCKLE	369	3
20-01N-02W	SOHIO 1 MOORE	04430-05186	*	ARBUCKLE BASEMENT	993	1

NOTE: THE ASTERISK (*) AFTER THE DEPTH RANGE INDICATES CORE CHIPS.

VELMA FIELD

LOCATION	WELL NAME	DEPTH RANGE		FORMATION	FILE#	BOXES
11-01S-05W	GULF 1 DOMA	02166-02174		PENN	94	3
11-01S-05W	GULF 1 DOMA	04792-05272			315	70
11-01S-05W	GULF 2 DOMA	03405-05730			1539	36
02-02S-05W	GULF 8 BROWN	00411-00451		PONTO SD ✓	1655	13

EOLA FIELD

LOCATION	WELL NAME	DEPTH RANGE		FORMATION	FILE#	BOXES
07-01N-02W	SOHIO B1 FRANKLIN	06145-08235	*	SIMPSON	986	8
07-01N-02W	SOHIO B1 FRANKLIN	09537-10001	*	ARBUCKLE	987	6
07-01N-02W	SOHIO C-1 CASSELL	06980-09527	*	HUNTON SIMPSON	1008	2
07-01N-02W	SOHIO C-1 HARRELL	08663-10007	*	SIMPSON	982	3
07-01N-02W	SOHIO D-1 CASSELL	07023-08240	*	SIMPSON	996	3
07-01N-02W	SOHIO 1 FORD	06305-09150	*	SYCAMORE HUNTON SIMPSON	1031	11
07-01N-02W	SOHIO 1 FREEMAN	06679-06691	*	VIOLA	995	1
07-01N-02W	SOHIO 1 HENTHORNE	03785-08880	*	HUNTON SIMPSON	103A	41
07-01N-02W	SOHIO 1A FRANKLIN	08561-09568	*	SIMPSON	985	3
07-01N-02W	SOHIO 2 FREEMAN	05306-07964	*	HUNTON SIMPSON	1002	8
07-01N-02W	SOHIO 2 HARRELL	07251-09267	*	HUNTON SIMPSON	983	6
07-01N-02W	SOHIO 3 HARRELL	07477-08266	*	SIMPSON	984	2
08-01N-02W	REPUBLIC 1 HARMON HEIRS	09009-09285	*	SIMPSON	1031	7
08-01N-02W	SOHIO 1 FIRST STATE BANK	08619-09512	*	SIMPSON	1005	2
08-01N-02W	SOHIO 1 SHIPLEY	06310-09745	*	HUNTON SIMPSON	1009	3
17-01N-02W	PAN AM 1 WILLIAMS	06901-06917		SIMPSON	372	3
17-01N-02W	SOHIO B-1 HOWARD UNIT	07277-09668		HUNTON SYLVAN BROMIDE SIMPSON	454	20
17-01N-02W	SOHIO 1 DUNLAP	01075-10377		SIMPSON	448	55
17-01N-02W	SOHIO 1 DUNLAP	09895-09897	*	SIMPSON	977	38
17-01N-02W	SOHIO 1 HOWARD-C	10204-10310		SIMPSON	450	26
17-01N-02W	SOHIO 1 MCKEE	10127-10311		[illegible]	[illegible]	[illegible]

EOLA FIELD (CONT.)

LOCATION	WELL NAME	DEPTH RANGE		FORMATION	FILE#	BOXES
07-01N-03W	SHELL 1 SNODGRASS	05943-06386		ARBUCKLE	1311	12
12-01N-03W	SOHIO & STAOLIND 1 CARPENTER	09892-10744	*	SIMPSON	1004	2
12-01N-03W	SOHIO B-1 HARRELL	05428-09406	*	HUNTON VIOLA SIMPSON	981	12
12-01N-03W	SOHIO B-1 HARRELL	05428-09406	*		981	12
12-01N-03W	SOHIO D-1 HARRELL	03856-10063	*	SIMPSON	1003	5
15-01N-03W	MOBIL B-13 MAULDIN	04981-04999		BASEMENT ROCK	22C	6

NOTE: THE ASTERISK (*) AFTER THE DEPTH RANGE INDICATES CORE CHIPS.

VITA 3

Jerry Duane Ferguson

Candidate for the Degree of

Master of Science

Thesis: THE SUBSURFACE ALTERATION AND MINERALIZATION OF PERMIAN RED BEDS OVERLYING SEVERAL OIL FIELDS IN SOUTHERN OKLAHOMA

Major Field: Geology

Biographical:

Personal Data: Born in Winfield, Kansas, August 27, 1953, the son of Mrs. Dorothea M. Ferguson and J. B. Ferguson.

Education: Graduated from Seminole High School, Seminole Oklahoma, in May, 1971; completed requirements for a Bachelor of Science degree in geology from Oklahoma State University, Stillwater, Oklahoma, in May, 1975; completed requirements for the Master of Science degree at Oklahoma State University in December, 1977, with a major in geology.

Professional Experience: Graduate teaching assistant, Oklahoma State University, Stillwater, Oklahoma, August, 1975 to May, 1977; teaching assistant, Oklahoma Geology Field Camp, Canon City, Colorado, summers of 1975 and 1976.